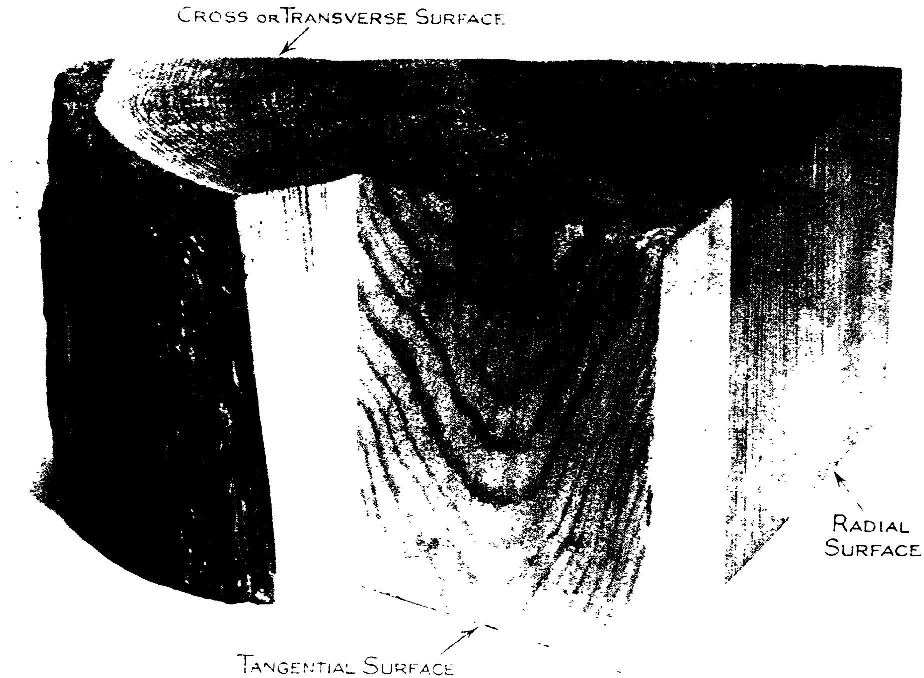
TIMBER

ITS STRUCTURE

AND

PROPERTIES



Softwood Timber showing the Relative Positions of Transverse, Tangential, and Radial Surfaces.

Photo by F.P.R.L., Princes Risborough.

TIMBER

ITS STRUCTURE
AND
PROPERTIES

BY

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THIS BOOK IS DEDICATED

TO

S. H. CLARKE, Esq., M.Sc.

IN APPRECIATION OF HIS ASSISTANCE
AND INVALUABLE CRITICISM
DURING THE PREPARATION
OF THE WORK

PREFACE

PERHAPS the most important factor in modern industrial development is the growth of research : no major industry, and few individual factories, are without a research organization whose function is to improve the quality of goods produced, and to point the way for extending markets by the adaptation of products to additional uses and ever-changing demands. The timber industry has a background of long-standing empirical practice on which to draw, and it is in rather a different position from most manufacturing concerns in that it has little or no say in the production side of its raw materials, and in the ordinary course of manufacture it does not appreciably change the nature of those materials. Nevertheless timber has not escaped the prevailing trend, and is to-day the subject of considerable intensive research, conducted in the main under Government auspices.

The pressing need for research arose during the War, when it became imperative to accelerate existing practice, without lowering quality, and to devise methods for selecting material for special purposes with precision. The foundation of the Forest Products Laboratory at Madison in 1916 was in direct response to the American Government's needs, and, although it was not until 1930 that the scattered sections of the Forest Products Research Laboratory of England were brought under one roof at Princes Risborough, work similar to that carried out at Madison had been in progress at the National Physical Laboratory, the Imperial Institute, and elsewhere, for some years.

Other laboratories devoted to the study of wood have been established in Canada, Australia, India, and Malaya, with the result that a wealth of accurate information has been amassed concerning the structure, properties, and treatment, of many timbers.

It was to be expected that some time would elapse before the industry fully appreciated the value of scientific information relating to a product so generally well known as timber, and the fact that the research was conducted by Government officers no doubt resulted in a certain amount of detachment on the part of the latter from purely practical points. The gap between the two bodies has been rapidly narrowing, as may be gauged from the astonishing growth of inquiries from trade sources received by the laboratories in recent years. One of the difficulties has been the dissemination of the information collected : much is in language too technical for the non-scientific man, and nearly all is distributed in separate bulletins, leaflets, and reports, which do not make for easy reference to particular points. Conversations with architects, surveyors, and building contractors, convinced the author that a simple, concise account of the work accomplished by Timber Research Laboratories, and of the knowledge now available concerning timber, would be of practical value. This conviction led him to write this little book.

An account of the structure, properties, and proper handling, of wood does not lend itself to a purely popular treatment, but technical terms have been avoided as far as possible. Whenever a term appears for the first time it is printed in heavy type, and its precise meaning is explained in the ensuing passage in the text. Such words only are indexed, so that the reader may refresh his memory as to their meaning at any time by reference to the index and the relevant section of the text. A list of botanical equi-

valents of the trade names used in the text constitutes the Appendix.

No claim of originality for the subject matter is made: it has been compiled from standard works, and the numerous publications issued from time to time by the different Research Laboratories. It is hoped, however, that the abridgement of existing information in a simple form between two covers will be found of some practical value. Passages in the section "Worm in Timber" (Chapter XI) are based on an article of the author's in the *Timber Trades Journal*, and are reproduced here with the consent of the Editor.

The author is particularly indebted to the kindness of several gentlemen who read the text in its different stages and offered much helpful criticism and advice. Professor Garratt of Yale, and Mr. F. G. Browne of the Malayan Forest Service, read the preliminary manuscript. Subsequently, in England, the manuscript was completely revised with the assistance of Mr. S. H. Clarke of the Forest Products Research Laboratory, Princes Risborough, without whose help this book would not have appeared. Finally, Mr. B. C. Adkin of the College of Estate Management, read the revised manuscript and made further valuable suggestions which have been incorporated in the text. Dr. R. N. Chrystal of the Imperial Forestry Institute has very kindly read the proofs. The author would like to record his appreciation of this invaluable assistance, although taking full responsibility himself for any errors that remain.

Several of the illustrations have been especially prepared for this book, but some have been loaned from other sources. The new photomicrographs were taken by Mr. L. H. Clinkard, of the Imperial Forestry Institute, from slides loaned by kind permission of Dr. L. Chalk. The original drawings are by Mr. J. Shaw, of the Imperial Forestry Institute, and Mr. Wong See Moy, of the Forest Research Institute, Kepong,

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H. E. DESCH

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May 1937

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PART I

THE STRUCTURE OF WOOD

CHAPTER I

INTRODUCTION

Wood is in such general use that it frequently escapes even passing notice, but those who have worked with the material are fully aware of its individuality. It is always possible, for example, to recognize a piece of oak or mahogany and to distinguish between these two timbers, but no two pieces of the same timber are exactly alike. The great variation in structure is part of the charm of wood, and accounts for its widely different uses, but in certain circumstances it places wood at a disadvantage in competition with other materials. To use wood to the best advantage it is necessary to understand its structure, and to know how and why that structure varies. This can only be done by seeking answers to such questions as: What is wood? How is it formed? And what purpose, if any, does it serve before it comes to the sawmill?

It is obvious that wood is produced by trees, not because of its usefulness to man, but because of its function, at one stage in its existence, as an integral part of a living plant, and the best approach to the study of wood is by way of the tree of which it was formerly a part.

THE TREE

Since Darwin first advanced his theories regarding evolution, it has become generally accepted that man has developed from more primitive ancestors, and that he represents the highest form of development in the animal kingdom. In the

same way advanced plants have evolved from earlier forms of plant life. Moreover, as in the animal kingdom today, where we find more primitive types existing side by side with the more advanced, so amongst plants the same conditions prevail.

To the botanist trees are more primitive than herbs, because the tree habit, or form of growth, is less efficient for maintaining the existence of a species. In Nature there is a continuous struggle between individuals for survival, and in the long run it is only the more efficient that prevail. Fitness for the continuous war depends on rapid reproduction of individuals to make good the losses sustained in battle. Most herbs grow from seed and develop and produce new seed in a single season, whereas trees require several seasons to mature, before reproducing their race. Much energy is used in producing a massive stem, which in herbs is devoted to the reproduction of the species. In consequence, but for man's interference, the more effective " economy ", and rapid reproduction, of herbs might result in their effacing trees from the earth, although the process might well take millions of years.

Another aspect of the struggle for survival that is always in progress in Nature, that is of considerable practical importance to those concerned with the growing of timber, is the struggle between individuals for the same area of ground, and the air space and light above. The forester makes use of the natural tendency of plants to compete against their neighbours by growing his trees close together so as to obtain the maximum volume of good-quality timber. The importance of the competition between individuals in producing clean, straight timber may readily be appreciated if the shape of a tree grown in park-land conditions be compared with one of the same species from high-forest: the former is stunted and has a low branching crown, and the latter is tall and straight and the bole is clear of branches to a considerable height. From the economic standpoint, the forest-grown tree produces a greater volume of better quality timber than the park-land tree.

The tree habit, then, is a mode of growth assumed by certain plants to enable them to outwit their neighbours in the struggle for air and light, which is essential to the development of an individual, and its subsequent duty of reproducing its kind. It is not the most efficient mode of growth from the plant standpoint, but it results in the production of timber, useful to man.

CLASSIFICATION OF TREES

Commercial timbers fall into two main groups, the " **softwoods** " and " **hardwoods** ", and the trees which produce these two different classes of timber are themselves quite distinct. The former are known as **gymnosperms**, *i.e.*, **conifers** or cone-bearing plants, characteristically with needle-shaped leaves, and seeds which are not enclosed in a seed-case ; the latter belong to a group known as the **angiosperms**, *i.e.*, **dicotyledons** or **broad-leaved** plants, characteristically with broad leaves and seeds enclosed in a seed-case. Although the division into " softwoods " and " hardwoods " is a convenient one for differentiating two broad classes of timber, there are a few timbers, *e.g.*, pitch pine, among the softwoods which are actually harder than other timbers classed as hardwoods, *e.g.*, lime, willow. Further, the divisions are not always applied correctly, particularly in the tropics. For example, native soft woods in such regions are usually soft " hardwoods ", that is, they are broad-leaved species with soft wood, and true " softwoods " may not occur.

The main groups of plants have been divided by botanists into smaller units called **families**, the families are further subdivided into **genera**, and the genera into **species**. Every plant has one **botanical name** made up of two parts, the first indicates the genus and the second the species ; these names are, by general consent, always in Latin.

NOMENCLATURE

The system of classification adopted by botanists is based on the characteristics of the tree as a whole, and not merely on timber characters, so that the larger units may contain widely different kinds of timbers ; within the smaller units, however, the resemblance between the different members is usually fairly close. For example, the true oaks, beech, and sweet chestnut, belong to one family, the *Fagaceae* ; the oaks constitute one genus, *Quercus*, beech a second, *Fagus*, and sweet chestnut a third, *Castanea*. The different kinds of true oak, *e.g.*, red oak, American white oak, Turkey oak, are separate species of the genus *Quercus*. Trade practice does not always follow botanical classification. The timber of any species may have several **vernacular names** and one or more **trade names**. *Quercus roburl.*, for example, is the botanical name of a common timber tree in this country ; the vernacular name of the timber is *oak*, and the trade name *English oak*. The vernacular name of the same timber in France, on the other hand, is *chêne*, and in Germany *Eiche*. Sometimes the timbers of several distinct botanical species have the same vernacular or trade name. There are, for example, several species of *Quercus* in different parts of the world and the timbers of all of them are known here as " oak " with or without a qualifying adjective, but in their countries of origin they may be known by different vernacular and trade names.

The nomenclature of timbers is further complicated by the practice of borrowing names of familiar and well-established timbers, and applying them to other and quite distinct woods. It has been computed, for example, that the name " mahogany " has been applied at some time or another to the timbers of more than 300 distinct botanical species, and the name is in common use today for several quite distinct groups of timbers. The original " mahogany " of commerce is the Spanish mahogany of today, and Honduras mahogany is a very close relative, being the timber

of a different species of the same genus. African mahogany, however, is produced by several species of two different, but closely related genera, belonging to the same family as the American species. Philippine mahogany, on the other hand, is produced by several species of more than one genus belonging to a different family altogether. In consequence, timbers bearing the name " mahogany " vary appreciably in their appearance and properties, and some have no real claim to be considered in the same class as the true mahogany. Similar confusion has arisen through the widespread use of such names as walnut, ash, oak, and teak.

Attempts are being made to standardize trade names. The British Standards Institution, for example, has published a list of standard names for softwood timbers, and the Empire Forestry Association has issued lists of Empire hardwoods.

DIVISIONS OF THE TREE

Almost all plants with which we are familiar have three main parts : roots, stems, and leaves. The characteristic which separates trees from other plants is that they have a single main stem, the trunk or bole.

Each of the three parts is specially adapted to a particular function : the roots anchor the plant in the ground, and take in water and mineral salts in dilute solutions from the soil : the stem conducts these solutions from the roots to the leaves, it stores food materials, and it has mechanical rigidity, supporting the leaves above competing vegetation : the leaves absorb gases from the atmosphere and, with the energy obtained from sunlight, manufacture complex substances for carrying on the life processes (Fig. 1). In passing it is worth noting the striking difference between the nutrition of plants and that of animals : the latter have to take in food in the manufactured state, and the former build up the complex substances they require from simple compounds.

The timber user is interested primarily in the trunk or bole. This bole has an outer covering, called the bark, which

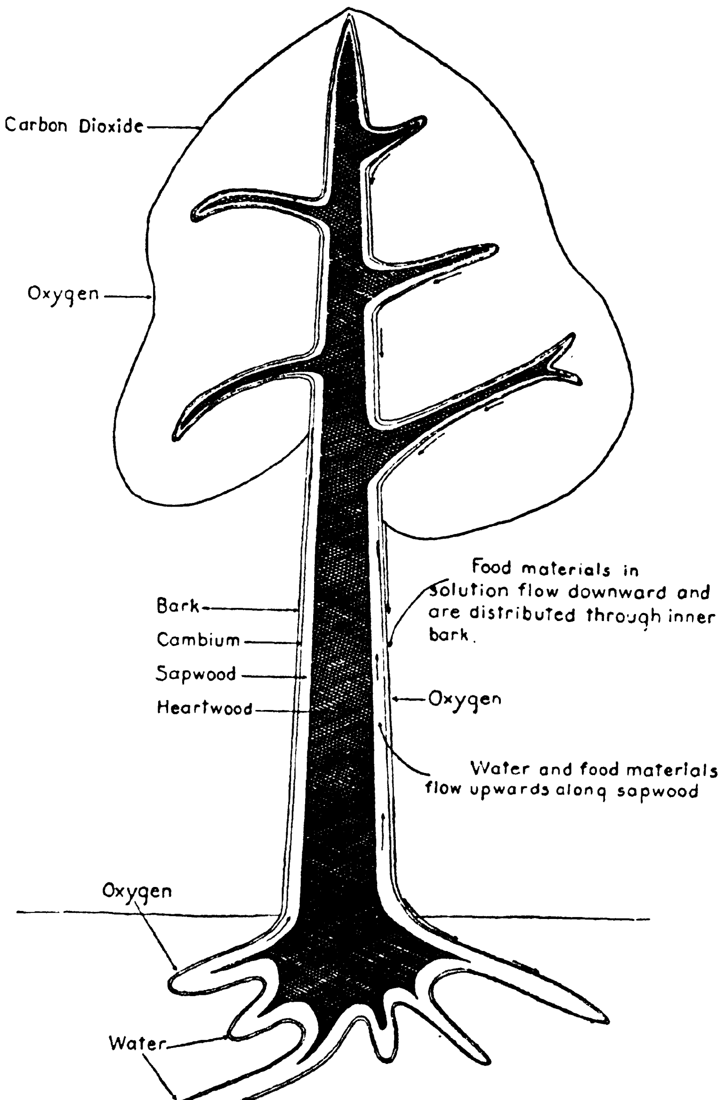


FIG. 1.—DIAGRAM showing main parts of a tree and how food is manufactured and distributed.

By courtesy of the Canadian Forest Service.

protects the wood from extremes of temperature, drought, and mechanical injury. The inner layers of the bark conduct the food manufactured in the leaves to regions of active growth and into places where it can be conveniently stored. The bark being a conductor of food materials is often rich in chemical substances such as tannin and dyes.

Between the bark and the wood is a thin, delicate tissue known as the **cambium**, which forms a complete sheath covering the bole and branches. This tissue produces bark towards the outside and wood towards the inside of the tree, and the enlargement in girth of the trunk is due entirely to the activity of the cambial sheath. The production of wood and bark tissue only occurs when the cambium is growing : in temperate regions this is during the spring and summer months. In this period the bark may easily be peeled, owing to the cambial tissue being less rigid and more easily torn than during the non-growing seasons, when it is tough and strongly attached to the bark and wood tissue.

DIVISIONS OF THE STEM

Further study of the structure of the bole can be pursued only in a felled tree. Under the bark is the cylinder of wood, and in the centre of this cylinder is the **pith** (Fig. 2), which may be up to $\frac{1}{2}$ in. in diameter, but in many trees is barely visible. A cross section of a branch is similar to that of the main stem, but that of a root differs in having little or no pith.

If the end surface of the bole is planed, further details of the wood structure can be seen : the wood consists of a series of concentric layers of tissue, called **growth rings** (Fig. 2). Each **growth layer** comprises the wood produced by the cambium in a single growing season. The rings are actually layers of wood, extending the full height of the tree, a new layer being added each growing season, like a glove, over the whole tree. Thus the wood nearest the outside of the bole is the youngest. In temperate regions and certain tropical

countries the alternation each year of a growing season followed by a resting period results in the growth rings being annual rings, thus providing a fairly accurate means of arriving at the age of a tree after it is felled. Double (or multiple) rings, consisting of two or more false rings, caused by serious interruptions to growth during the growing period, sometimes cause errors in such calculations. Where growing seasons are not well defined (as in many tropical regions) growth rings may be indistinct or absent.

In many species the wood produced at the beginning of the growing season is different in character from that formed later in the season, and zones of **early wood** [1] and **late wood** [1] may be distinguished. Where this is the case the early wood is softer, coarser, or more porous, than the late wood.

The work of food storage and sap conduction is performed in most trees only by the outer, or youngest, growth rings; these are known as the **sapwood**. The sapwood forms a distinctive zone which may be several inches wide, according to the species and age of the tree, and the mode of growth of individual trees. Trees of the same age and species have a wider zone of sapwood when grown in the open than when grown under forest conditions in close competition with other trees. The central part of the tree is concerned with providing mechanical rigidity to the stem and support for the crown; it is known as **heartwood**.

The sapwood is usually lighter in colour than the heartwood and less durable, and, when green, contains much more moisture. The line of demarcation between the two zones may be sharply defined or indefinite, and in some species there is no colour differentiation between the two: such trees are popularly spoken of as "all-sapwood" trees, although this is not an accurate description. In many trees the conducting channels are blocked in various ways when the wood becomes heartwood, and any remains of stored food material become changed to tannins and other substances;

[1] The early wood is sometimes called **spring wood**, and the late wood, **summer** or **autumn wood**.

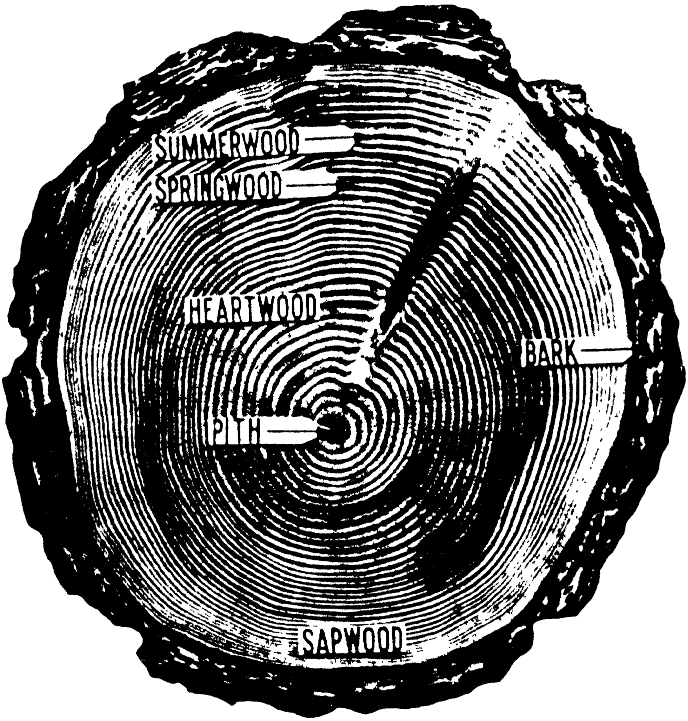


FIG. 2. CROSS SECTION OF SOFTWOOD LOG, showing bark, wood, and pith.

By courtesy of the Canadian Forest Service.

it is to these changes that the heartwood owes its durability. In the absence of colour differences such changes are an indication of transition to heartwood.

THE UNITS COMPOSING WOOD

Like all plants, and for that matter animal tissue, wood is built up of individual units called **cells**. These units are either tube-like, with blunt or pointed ends, or brick-shaped. They may be empty or filled with various kinds of solid or semi-solid substances. Cells differ considerably in size and shape, and each is adapted to one or more of the three primary functions of the stem. The majority are invisible to the naked eye, varying from 0·001 to 0·02 in. in diameter.

The formation of cells is a " vital " or " living " process which we describe as "**growth**", the increase in size of plants being due to the formation of additional cells much more than to the enlargement of existing ones. Growth in plants is restricted to regions where cell-forming tissue occurs. The main stem and branches of a tree increase in length solely at their tips,[1] and growth in thickness occurs in the sheath of cambial tissue, one or more cells thick, situated between the bark and wood. Growth in thickness continues after height growth has practically ceased, and up to the time the tree dies.

New cells arise as a result of the repeated division of the cambial cells. Before division occurs these cells swell, and certain changes take place in their contents. Partition walls are then formed, either in the longitudinal, oblique, or horizontal planes, dividing each cell into two. The longitudinal division gives rise to cells of the bark and wood, and the oblique or horizontal division adds cells to the cambial sheath,

[1] The growing tip of the main stem and branches is composed of (1) **meristematic** cells of the apex and (2) the **pro-cambial strands** derived from normal meristematic cells and situated immediately below the growing tips. Growth in length is due to activity in the region of the pro-cambial strands. These strands give rise later to isolated patches of cambial cells which eventually link up to form the cambial sheath.

necessitated by the increase in circumference of the bole as growth proceeds. The two cells that result from longitudinal division are identical at first, but their subsequent development is different. One, after enlargement to the size of the original cambial cell, divides again, while the other develops into either a unit of the **secondary xylem** (wood tissue) or a unit of the **phloem** (bark tissue). The two cells that result from oblique or horizontal division of a cambial cell, on the other hand, merely increase to the size of normal cambial cells, when they undergo longitudinal division to form bark or wood cells in the manner described.

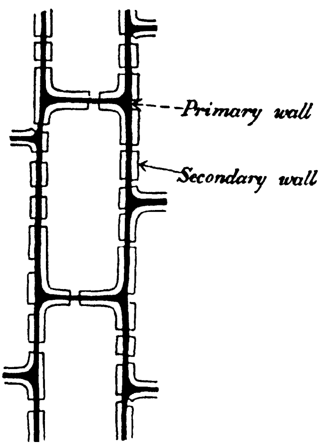


FIG. 3.—A CELL showing the primary and secondary walls (much enlarged).

The secondary xylem is the timber of commerce, and our study will be confined to the cells that compose it. These cells develop rapidly after formation, completing the process in a few weeks, after which the majority die and undergo no further change in size or shape. Those that remain alive assist in growth, *e.g.*, by storing food, and when no longer required for this purpose they also die. In other words, the bulk of the stem and branches of a living tree is composed of dead cells.

When first formed, the young cell is in a plastic condition and capable of considerable increase in size and change in shape, rather like a partially inflated balloon. Increase in size and change in shape is rapid, and when the final size is attained the walls are thickened by the addition of further layers of wall substance laid down from the inside of the cell. The original unthickened wall is called the **primary wall**, and the layers added afterwards constitute the **secondary wall** (Fig. 3).

Unthickened gaps, called **pits**, are left in the primary wall during the formation of the inner layers, and these serve as means of communication between cells : liquids moving in the tree pass mainly through the pits. The pits of different types of cells show modifications in their structure, which increase their efficiency in controlling the movement of

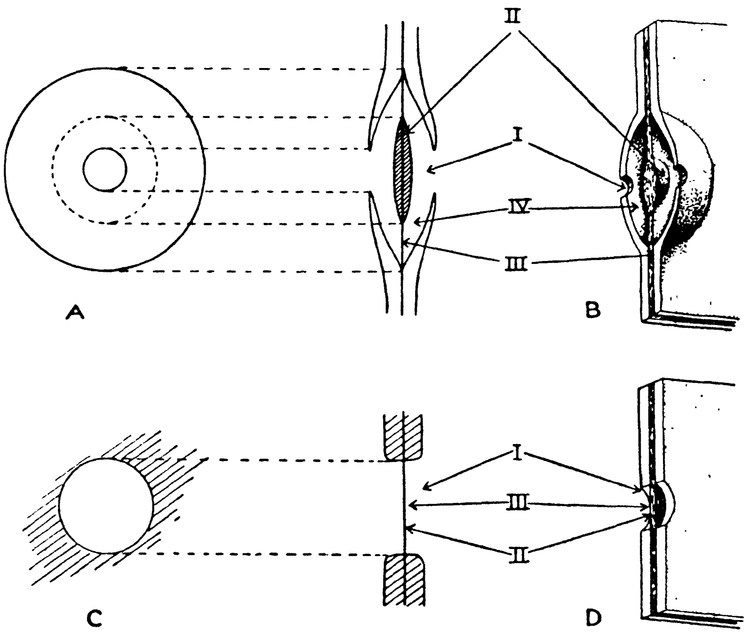


FIG. 4.—A, SURFACE VIEW AND SECTION THROUGH PITS IN CONDUCTING CELLS; B, SOLID VIEW OF TWO PITS CUT IN HALF (after a woodcut by Dr. L. Chalk): I, pit opening; II, torus; III, primary wall; IV, pit cavity (much enlarged); C, SURFACE VIEW AND SECTION THROUGH PITS IN STORAGE AND STRENGTHENING TISSUE; D, SOLID VIEW OF TWO PITS CUT IN HALF: I, pit opening; II, primary wall; III, pit cavity.

liquids into and out of the cells (Fig. 4). As might be expected, conducting cells have more pits than those concerned with the provision of mechanical rigidity, and the pits are specially adapted for controlling the movement of liquids in these cells.

With the formation of the secondary walls, chemical

changes occur which increase their rigidity. Among the substances formed is **lignin**, which gives its name to the process : **lignification.** Lignification should not be confused with the changes which take place in the transition from sapwood to heartwood. The former is dependent on the cell being alive, whereas the latter can occur in dead cells, since it is confined to changes in the contents of the **cell cavity** (the space enclosed by the cell walls), and the addition of infiltrates to the cell wall which do not alter the chemical composition of the existing wall-substance.

We have learned that the stems of trees perform three functions and that these are carried out by different types of cells. A group of similar cells performing the same function is called a **tissue**, thus we may speak of the storage tissue, the conducting tissue, and the mechanical or strengthening tissue.

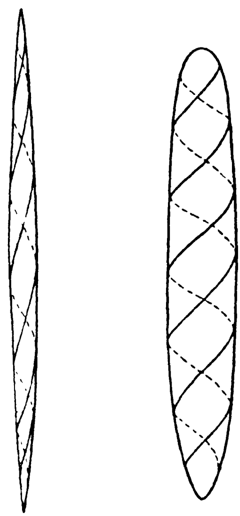
THE COMPOSITION OF CELL WALLS

The cell walls of all plants may be visualized as series of thin, concentric layers or sleeves. The individual layers are composed of spiral, thread-like strands, known as **fibrils** (Fig. 5), which may be likened to valve springs making one or more turns in the length of a cell. The fibrils in turn are composed of minute, spindle-like units, called **fusiform bodies**, which consist of still smaller particles, called **spherical units.** The ultimate composition of the spherical units are the molecules of **cellulose**, a substance composed of carbon, hydrogen, and oxygen.

The purest form of cellulose in plant tissue is cotton ; actually the hairs of the cotton seed, which are individual cells. In the cells of wood, cellulose is associated with other substances, the most important of which is lignin. To this latter substance wood owes its stiffness. Nevertheless, the cellulose of wood is chemically identical with that of cotton, and various methods are employed commercially to remove the other constituents of the cell wall, leaving a fairly pure

form of cellulose. The resultant substance is the raw material of the chemical paper-pulp and artificial silk industries.

In addition to cellulose and lignin, which are the main constituents of the cell walls of *all* woods, other substances, spoken of as **infiltrates**, are present in the cell walls and cell cavities of *some* woods. These infiltrates have an important bearing on problems of utilization. For example, tannin renders the heartwood of oak durable, and black-coloured infiltrates are responsible for the decorative appearance of ebony. On the other hand, the absence of such infiltrates is of great importance to the manufacturers of paper pulp and artificial silk, and the presence of gums and resins may adversely affect the working and painting qualities of timber. Even in extreme cases, however, infiltrates rarely exceed 10 per cent. of the dry weight of wood, and more usually account for only 2 to 3 per cent.



A B

FIG. 5.—DIAGRAMMATIC DRAWING showing the spiral alignments of fibrils in the cell wall.
By courtesy of A. Koehler, Esq.

The chemical composition of cell walls influences strength properties, working qualities, and utilization of timber, and the physical structure accounts for certain other properties of wood, *e.g.*, electrical conductivity and insulating properties, and its behaviour in relation to changes in atmospheric conditions.

CELL CONTENTS

In addition to the "living" content or **protoplasm** of all living cells, **crystals** of calcium oxylate, deposits of **silica** (Fig. 6), and plant food materials may occur in the storage

tissue of both sapwood and heartwood, and gums and other solid deposits in the vessels of the heartwood. Plant food materials are of particular importance, because in some forms they are the food of certain insects and fungi that attack wood, and in other forms they are actually repellent to such foes. For example, starch, which only occurs in any quantity

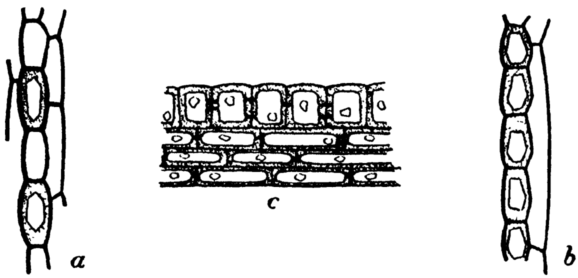


FIG. 6.—*a* and *b*, Crystals in wood-parenchyma cells; *c*, deposits of silica in ray cells.

in the sapwood, is an essential food of powder-post (*Lyctus*) beetles and sap-stain fungi, and the aromatic oils that occur in the heartwood of some timbers are toxic to fungi and insects.

The foregoing pages have dealt with the structure of wood in outline; the next two chapters deal with the structure of the different kinds of cells in greater detail. As the tissues of softwoods are simpler in many respects than those of hardwoods they are described first.

CHAPTER II

SOFTWOOD TISSUES

THE CONDUCTING AND STRENGTHENING TISSUE

In softwoods the conducting and mechanical functions are performed by a single type of cell known as **tracheids**. These are hollow, needle-shaped units attaining as much as 0·4 in. in length, but more usually varying from 0·1 to 0·2 in. They are packed closely together so that a cross section through them resembles a honeycomb (Fig. 7).

Examination of Fig. 7 reveals differences in thickness of cell walls, and consequently in size of cavities. It will readily be appreciated that the larger the cavity the better is the cell fitted for conduction, and conversely the thicker the walls the more suitable are the cells for strengthening purposes. In the tree the thin-walled tracheids with large cavities are primarily concerned with the conduction of sap, and the thick-walled ones with maintaining mechanical rigidity, although they may play some small part in conduction. Radial sections of softwoods show a second modification of structure between the thin- and thick-walled tracheids (Fig. 8). In this figure it will be seen that the pits in the thinner-walled tracheids are larger and more numerous than those in the thicker walls of the strengthening cells.

If we turn to Fig. 7 again, a further and conspicuous feature of the wood structure of softwoods may be noticed. The distribution of thin- and thick-walled tracheids is not haphazard, they occur in alternating zones, the conducting tracheids being laid down at the beginning of a growing season, when the water requirements of the leaves are at a

maximum, whereas the strengthening ones are formed later. This arrangement, incidentally, renders growth rings in softwoods conspicuous to the naked eye ; the early wood, containing a smaller proportion of wall substance, appears lighter in colour than the denser late wood. In some species the transition from thin- to thick-walled tracheids is abrupt, *e.g.*, larch, Douglas fir or Oregon pine, but in others, *e.g.*, white pine and the true firs, it is gradual.

The quality of a softwood depends largely on the proportions of thin- to thick-walled tracheids, and on the contrast between the wood of these two zones. The higher the percentage of late wood the stronger is the timber ; moreover, marked differences in thickness of the walls of the early and late wood cells may cause the two zones to behave differently under tools and in service, and may give rise to painting problems, *e.g.*, as in Douglas fir.

In popular language tracheids are often called " fibres ", particularly in connection with wood-pulp in the paper industry, but this is incorrect, true fibres occur only in hardwoods.

THE STORAGE TISSUE

The storage tissue consists of two kinds of cells which are essentially similar in details of structure, but which differ in their manner of distribution in the wood. These cells are brick-shaped, with the longer axis horizontal in the **ray-parenchyma** cells, and vertical in the **wood-parenchyma** cells. The cells have relatively thin walls with numerous pits. They differ from tracheids in remaining alive for some years after their development is completed. This is because plant food is usually stored in some form other than that required by the growing cambium, and its conversion to a suitable state can only occur in a living cell. When no longer required for storage the parenchyma cells die like any other cells of the secondary xylem.

The ray tissue occurs in narrow, horizontal bands called **rays** (medullary rays), which radiate outwards from the centre

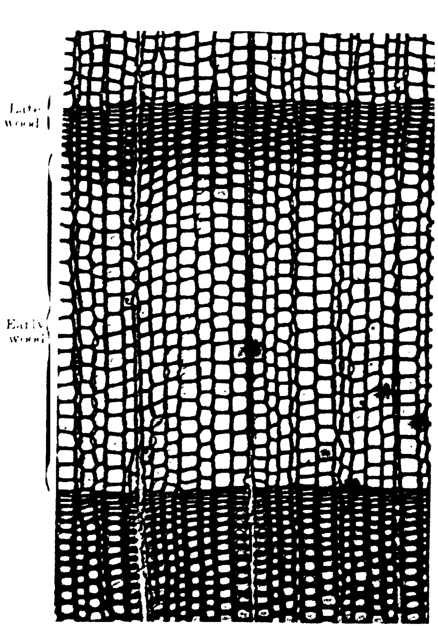


FIG. 7. TRANSVERSE SECTION OF SCOTS PINE (× 75) showing one complete growth ring. Note the thin walls of the early wood tracheids and the thick walls of the late wood and the abrupt change from early to late wood.

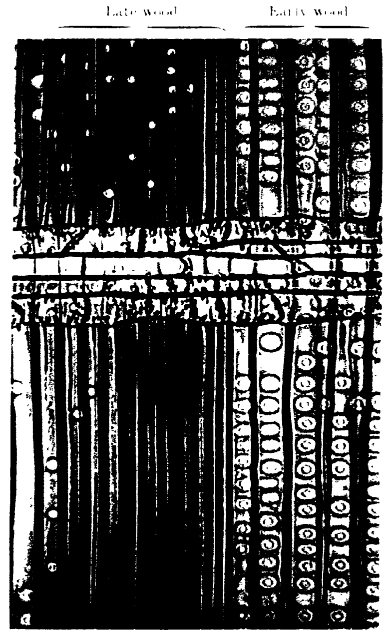


FIG. 8. RADIAL-LONGITUDINAL SECTION OF SCOTS PINE (× 150). Note the numerous and large pits in the early wood, and the few small pits in the late wood.

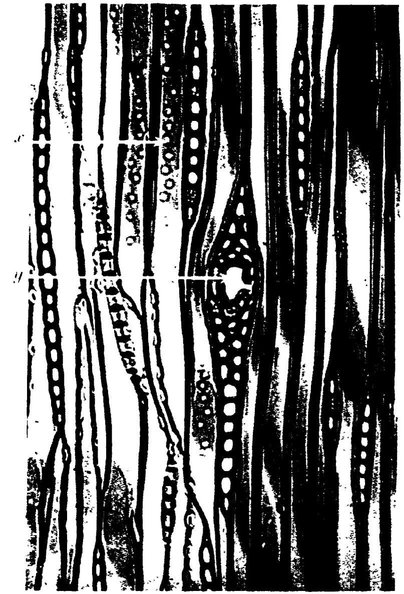


FIG. 9. TANGENTIAL-LONGITUDINAL SECTION OF SCOTS PINE (× 150). Note the small pits in the late wood (x) and the resin canal in the ray (y).

Photos by L. A. Clinkard.

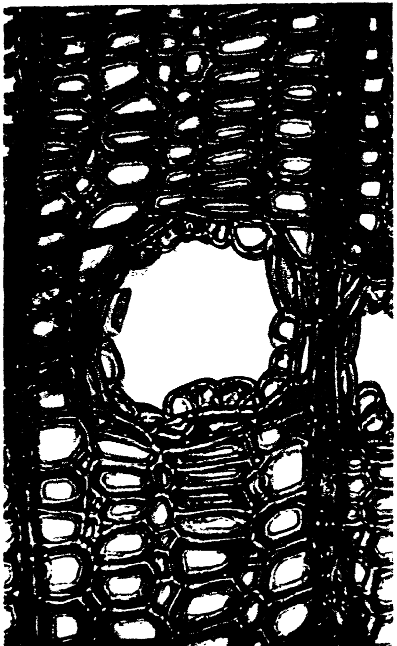


FIG. 10.—TRANSVERSE SECTION OF SCOTS PINE (about × 300) showing a vertical resin canal.

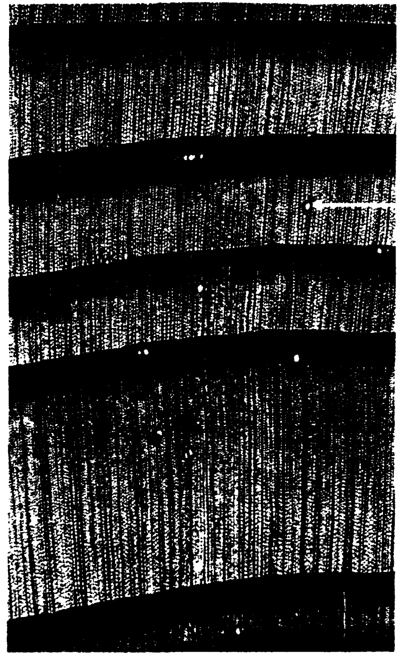


FIG. 11.—TRANSVERSE SECTION OF LARCH (× 10) showing normal distribution of vertical resin canals.

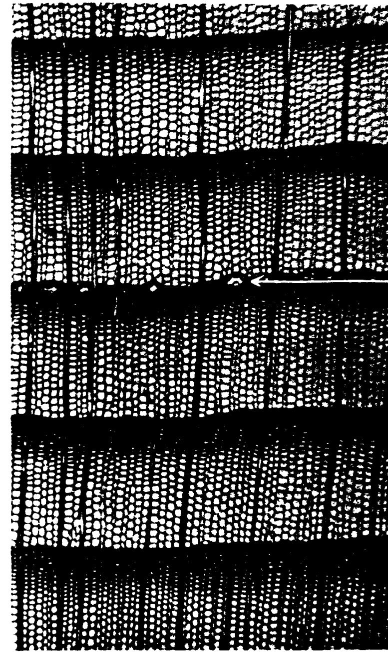


FIG. 12.—TRANSVERSE SECTION OF CEDAR (× 10) showing a tangential series of traumatic resin canals.

of the tree to the bark, although on a small area from near the outside of a large tree they may appear as a series of parallel layers between several rows of tracheids as in Fig. 7. These bands are continuous outwards because the cambial cells from which they arise produce only ray cells at each division, and never wood-parenchyma cells or tracheids.

The rays are usually just visible to the naked eye on radial surfaces, where they appear as narrow, horizontal ribbons 0·002 to 0·02 in. wide (Fig. 8). They may appear discontinuous because the cut surface is rarely truly radial and the rays may run out of the section.

On end and tangential surfaces the rays can usually be seen with the aid of a low-power lens. On end surfaces they appear as narrow lines radiating outwards, crossing the growth rings at right angles, and on tangential surface (Fig. 9), where the rays themselves are seen in section, they appear as short, vertical lines.

The wood-parenchyma cells are derived from normal cambial cells that also produce tracheids. After longitudinal division of a cambial cell, the cell that is to become a unit of the storage tissue divides transversely one or more times to give a vertical series of cells. The individual cells are wood-parenchyma cells, and the series is known as a **parenchyma strand**. Several strands may be united end to end.

In softwoods the wood-parenchyma tissue is sparse in amount, and visible only under the microscope. The strands are scattered through the wood, or restricted to definite zones, or in a layer at the end of a season's growth.

RESIN CANALS AND " PITCH POCKETS "

A characteristic feature of many softwood timbers is their resinous nature, which is often sufficient to give them a pronounced odour, and may cause freshly sawn timber to be " tacky ". The resin is formed in parenchyma cells, and in some species occurs in special channels called **resin canals** or **resin ducts**. These canals are not cells, but cavities in the

wood, lined with an "**epithelium**" of parenchyma cells. The epithelial cells secrete resin into the canals.

Resin canals run vertically in the stem and horizontally in the rays, and are just large enough to be seen with the naked eye. They are a useful feature for distinguishing some timbers, since they are always present in some species, *e.g.*, the larches, Douglas fir (Oregon or Columbian pine), the true pines, and spruces, but are normally absent in others, *e.g.*, the true firs and Californian redwood (Fig. 10).

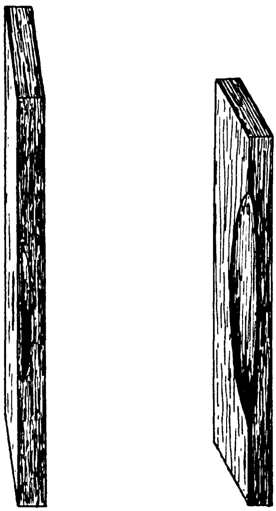


FIG. 13.—PITCH POCKETS IN DOUGLAS FIR (considerably reduced).

Vertical resin canals may develop as the result of injury to the tree, in timbers from which they are normally absent, as well as in those of which they are a normal characteristic. Such canals are said to be **traumatic**; they differ from normal canals in that they occur in short or long rows parallel to the growth rings (as seen on transverse section), whereas the normal canals are scattered in distribution (compare Figs. 11 and 12).

Serious injury to the cambial cells may result in the formation of "**pitch pockets**" (Fig. 13). These vary in size from about $\frac{1}{8}$ in. to several inches wide tangentially, and up to a foot or more longitudinally. They are saucer-shaped, with the concave face towards the pith, and up to an inch or more at their greatest depth radially. They contain liquid resin which flows out readily when the pockets are sawn through. Openings of the wood along the growth rings may also become more or less filled with pitch in a liquid or granulated state, these are known as **pitch-seams** or **-shakes**.

CHAPTER III

HARDWOOD TISSUES

TYPES OF CELLS IN HARDWOODS

WHEREAS in softwoods both conduction and strengthening are undertaken by a single type of cell, in hardwoods there is a more distinct division of labour, and the conducting cells, called **vessels** or **pores**, are quite different from those that provide mechanical support. The distinctive conducting tissue provides a simple way of recognizing hardwoods. The cambial cells of hardwoods are shorter than those of softwoods, and so are the mature cells that arise from them. The maximum length rarely exceeds 0·008 in. as compared with 0·4 in. attained by some softwood tracheids. In hardwoods, as in softwoods, the same cambial cell may give rise successively to conducting, mechanical, or storage cells, and a special type of cambial cell gives rise only to ray cells.

THE CONDUCTING TISSUE

The counterpart in hardwoods of the thin-walled, conducting tracheids of softwoods are the vessels or pores, illustrated in Fig. 14. This figure shows a vertical series of three fully-developed conducting cells, each of which is known as a **vessel member**. These members are always produced in vertical series, which may extend for a considerable distance in the tree. In Fig. 14 it will be seen that the vessel members have no "end" or transverse walls, but are open top and bottom. When first formed these cells have end walls like other cells, but early in their development the cells

swell and the end walls disappear, so that the members form a continuous tube, like a drain-pipe, in the tree.

In some species, *e.g.*, birch, alder, American white wood, the whole of the end walls of the vessel members do not disappear; instead grid-like partitions, known as **scalariform perforation plates**, are left. These partitions are oblique, and are always arranged radially; they can be seen with a hand lens on split radial surfaces as in Fig. 15.

It will be clear that the conducting tissue of hardwoods is more effective in providing the water requirements of leaves than are tracheids in softwoods, and this is necessitated by reason of the larger leaf area of broad-leaved species compared with conifers. Moreover, in addition to the open ends of the vessel members, pits occur in the longitudinal walls, but these pits are smaller than those in the walls of softwood tracheids.

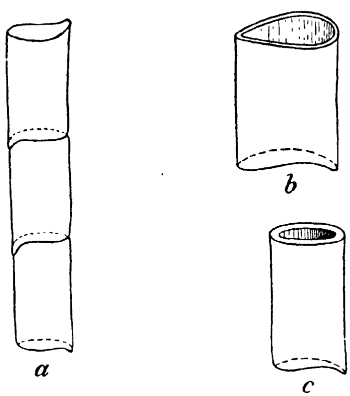


FIG. 14.—VESSEL MEMBERS. *a*, Vertical series of three vessel members; *b*, thin-walled early wood vessel member; *c*, thick-walled late wood vessel member. (Highly magnified.)

Some hardwoods, of which oak and sweet chestnut are examples, have tracheids in addition to vessels to assist in conduction. These tracheids are similar in appearance to softwood tracheids, but they are shorter, and the pits resemble those of vessel members, and are not restricted to the radial walls.

Vessels are distributed throughout the wood singly, or in radial or tangential groups, or in clusters (Figs. 16, 17, 18, 26). As a general rule those formed at the beginning of the growing season are wider and thinner walled than those formed afterwards. In some species the decrease in size is gradual throughout the ring; these are the **diffuse-porous** woods,

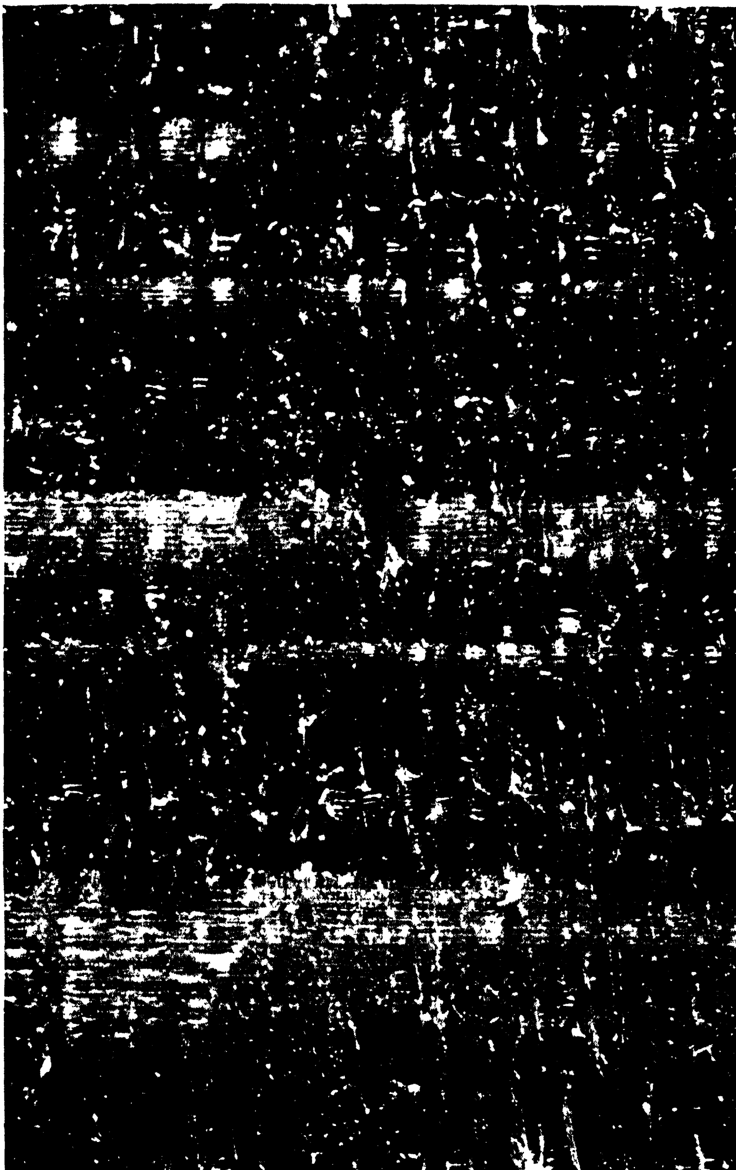


FIG. 15.—SCALARIFORM PERFORATION PLATES IN THE VESSEL MEMBERS OF TULIP WOOD (× 40), as seen with a lens on a radial face of the wood.

Photo by F.P.R.L., Princes Risborough.

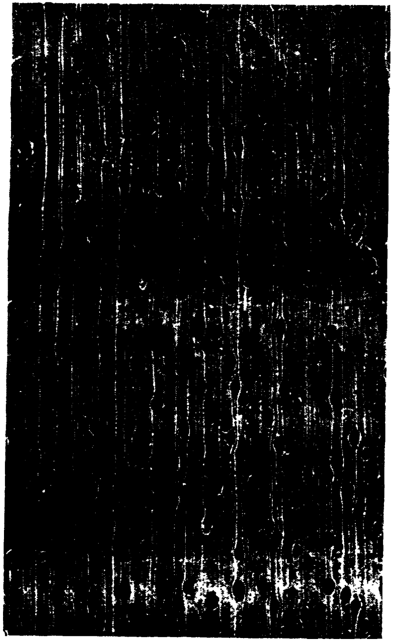


Fig. 16.—Transverse Section of Tasmanian Oak (mountain ash) (× 10) showing solitary vessels.

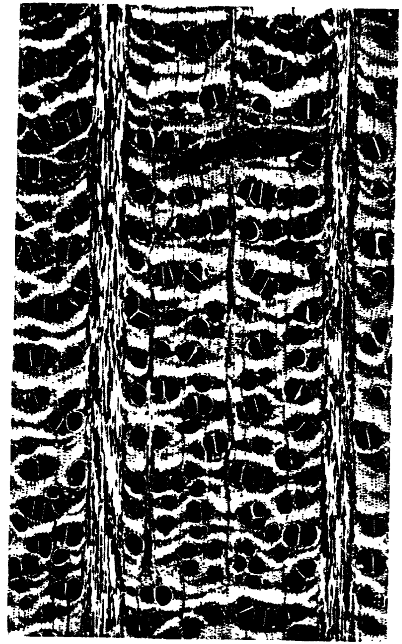


Fig. 17.—Transverse Section of Australian Silky Oak (× 10) showing tangential groups of vessels.

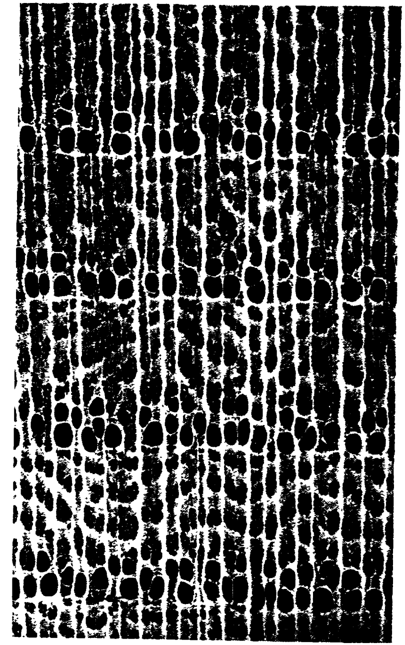


Fig. 18.—Transverse Section of Wych Elm (× 10) showing clustered ar-

e.g., beech, birch, poplar, sycamore, and the great majority of hardwoods (Fig. 20). In other species the vessels of the early wood are comparatively large, and there is an abrupt change in size to the small and thicker-walled vessels of the late wood; these are the **ring-porous** woods, so called because the early wood vessels form a distinct ring which can be seen with the naked eye on end surface, *e.g.*, oak, ash, elm (Fig. 21).

The vessels of the heartwood do not conduct, but are often blocked with what appear to be foam-like structures, known as **tyloses**, or they may contain solid deposits of a gummy type. Tyloses, as may be seen in Fig. 19, are ingrowing bladder-like structures from adjoining ray- or wood-parenchyma cells. Tyloses are important from the utilization point of view, because they impede the growth of fungi, the principal cause of decay in wood. The presence or absence of tyloses is also a useful character for distinguishing between certain woods. For example, they are absent from the true mahoganies (species of the genus *Swietenia*) and present in the lauans or "Philippine mahogany" (species of the family *Dipterocarpaceae*).

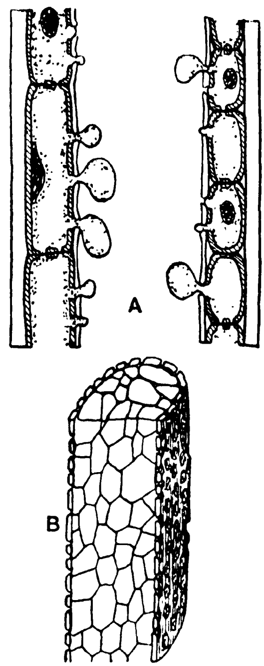


FIG. 19.—DIAGRAMMATIC DRAWING OF THE DEVELOPMENT OF TYLOSES: A, stage 1, development from storage cell through the pits into a conducting cell. B, stage 2, tyloses completely blocking a vessel.

By courtesy of Prof. Forsaith.

THE STRENGTHENING TISSUE

The mechanical tissue of hardwoods consists of **wood-fibres.** These are narrow, spindle-shaped cells, not unlike

the late wood tracheids of softwoods, but they usually have more pointed ends and are shorter. The walls of these cells may be comparatively thin, or so thick that the cell cavity is reduced almost to vanishing point (Figs. 22, 23, 24). In discussing the factors which affect the quality of softwoods, the importance of the proportions of thin- to thick-walled tracheids, the thickness of the walls, and the distribution of the different tissues was mentioned. In hardwoods the thickness of the fibre walls and their physico-chemical nature are in many cases the most important factors in determining the strength, shrinkage, and working properties, of these timbers.

Pits in fibre walls are fewer and smaller compared with those of other kinds of cells, and are not confined to one wall.

In some timbers, *e.g.*, teak, Gaboon mahogany, the cavities of the fibres are divided into small compartments by thin horizontal partitions ; such fibres are called **septate fibres**. The reason for the partitioning is not known, but such fibres are more common in species with little parenchyma.

THE STORAGE TISSUE

In hardwoods the storage tissue is essentially similar to that of softwoods, but it is frequently more abundantly developed and displays greater variety in distribution and arrangement. In consequence wood parenchyma and rays are among the most useful features for distinguishing between different hardwoods.

Wood Parenchyma.—Four distinct types of distribution may be recognized : **diffuse, terminal, metatracheal,** and **paratracheal,** and their appearance on end surface is described below.

Diffuse parenchyma consists of single strands distributed irregularly among the fibres, as in pear ; this type is usually visible only under the microscope (Fig. 26).

Terminal parenchyma is the name for the narrow layers of parenchyma cells occurring at the close of a season's

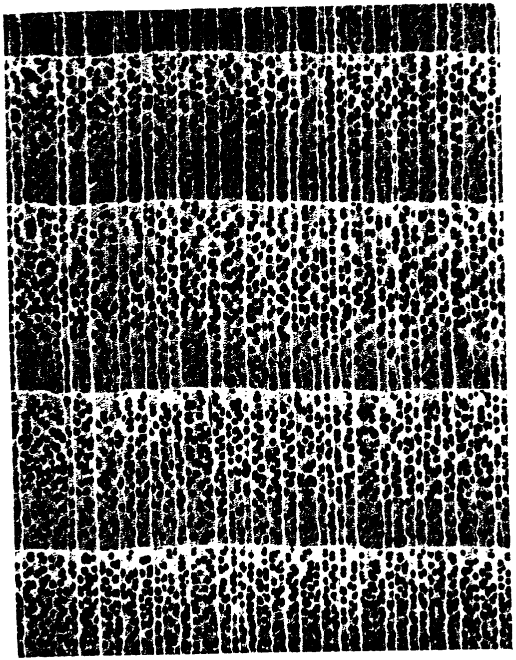


FIG. 20.—TRANSVERSE SECTION OF A DIFFUSE-POROUS WOOD—TULIP WOOD (× 10).

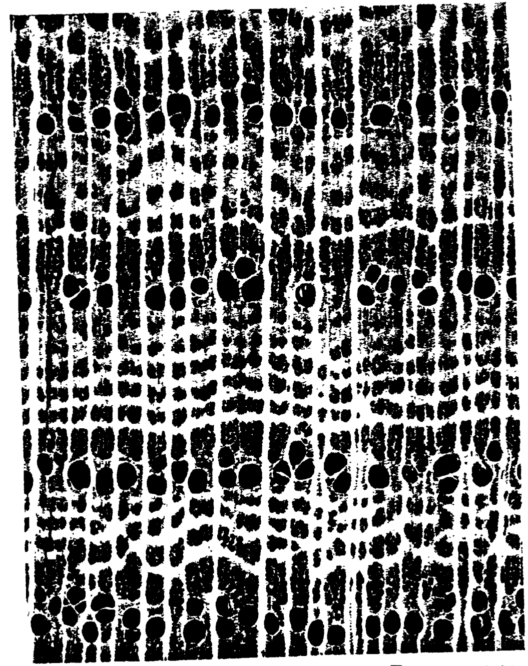


FIG. 21.—TRANSVERSE SECTION OF A RING-POROUS WOOD—ELM (× 10).

Photos by L. A. Clinkard.

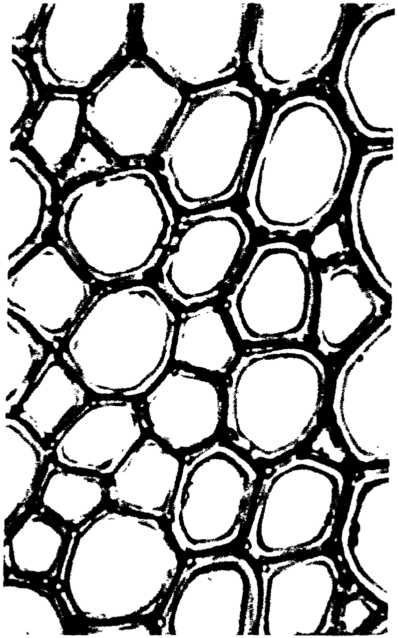


FIG. 22.—TRANSVERSE SECTION OF POPLAR (×800) showing thin fibre walls.

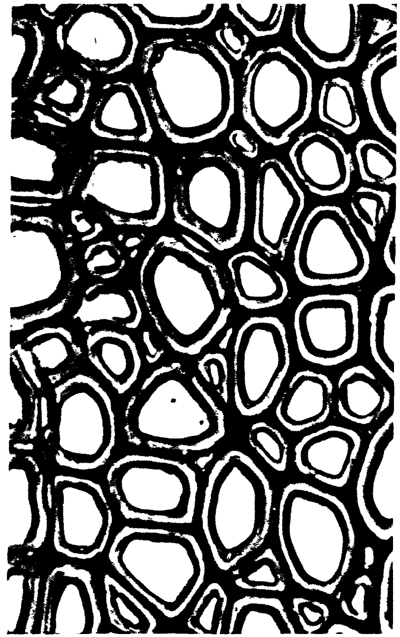


FIG. 23.—TRANSVERSE SECTION OF TEAK (×800) showing moderately thick fibre walls.

FIG. 24.—TRANSVERSE SECTION OF EKKI (×800) showing thick fibre walls.

Photos by L. A. Clinkard.

growth. If the layers are wide enough they may be visible to the naked eye as light-coloured lines marking the boundaries of the rings, as in sycamore (Fig. 27).

Metatracheal parenchyma occurs in tangential layers which are independent of the vessels. These layers appear as lighter coloured bands concentric with the growth-ring boundaries. They may be very narrow and only visible with a lens as in hornbeam, walnut, etc. (Fig. 28), or broad and conspicuous to the naked eye, as in "cherry mahogany" (Fig. 29). The individual bands vary considerably in length, the longer ones appearing on end surface as series of concentric rings. The bands sometimes branch and connect with adjoining bands at several points.

Paratracheal parenchyma.—Parenchyma associated with the vessels is said to be paratracheal; several types may be recognized. Where the tissue is sufficiently abundant as to form complete borders around the vessels, as in ash, it is said to be **vasicentric** (Fig. 30). In many timbers the borders extend tangentially in wing-like arrangement, and appear in cross section as diamond or lozenge-shaped masses containing the vessels as in merbau: this is **aliform parenchyma** (Fig. 31). When the tangential projections extend and link up with those of neighbouring vessels, as in the Indian rosewood, the parenchyma is said to be **confluent** (Fig. 32). Confluent parenchyma is sometimes not easily distinguished with a lens from broad bands of metatracheal parenchyma, but careful examination shows that the former type connects up or contains the vessel, and the latter is independent of the vessels coming in contact with them only by chance.

The arrangement of parenchymatous tissue is a useful aid in identifying many timbers: in some timbers only one type is present, but in others two or more types occur. In some, however, the arrangement is too variable to be of any value for identification purposes.

Rays.—Whereas in softwoods ray tissue is sparsely developed and typically only one cell wide in the tangential

direction, *i.e.*, **uniseriate**, in hardwoods there is a considerable variation both in size and number of the rays.[1] Some hardwoods have only uniseriate rays, *e.g.*, poplar and willow (Fig. 33, *a* and *b*), but in the majority the rays are **multiseriate**, *i.e.*, more than one cell wide. In some the rays are comparatively uniform in size; they may be relatively small, and not easily visible to the naked eye, as in birch (Fig. 34, *a* and *b*), or they may be broad and high, and conspicuous to the naked eye, as in beech (Fig. 35, *a* and *b*). In other woods rays of two distinct sizes occur: very large rays in association with uniseriate ones, as in oak (Fig. 36, *a* and *b*). In a few species groups of small rays occur in aggregations which appear to the unaided eye, or at low magnifications, as single large rays; these are known as **aggregate** rays. The apparently broad rays of hornbeam, alder, and hazel, are of this type (Fig. 37, *a* and *b*).

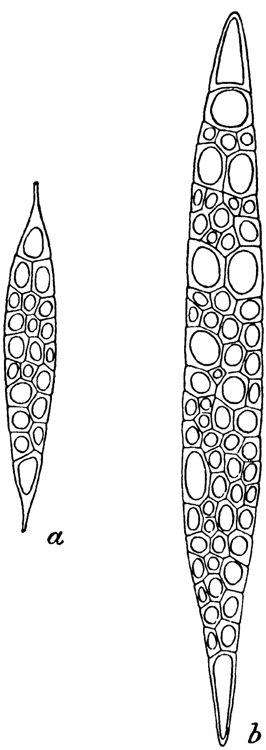


FIG. 25.—*a*, Homogeneous ray; *b*, heterogeneous ray (much enlarged).

Very broad rays give rise to the handsome "silver grain" of quarter-sawn timber of the true oaks and Australian silky oak. The presence of broad rays is also an indication that the timbers will split readily in a radial direction, an important property for certain specialized purposes, *e g.*, the best quality "tight" barrel staves.

Rays are sometimes arranged in regular storeys or tiers, which appear on tangential surfaces as parallel lines, known

[1] In softwoods ray tissue accounts for about 6 per cent. of the total volume of the wood; in hardwoods the figure is 18 per cent. and upwards.

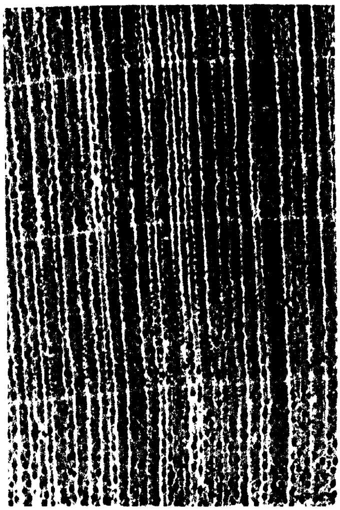


FIG. 26.—TRANSVERSE SECTION OF PEAR (× 15) showing diffuse parenchyma (the small white dots scattered through the wood). Note, also, the terminal parenchyma at the boundaries of the growth rings.

FIG. 27. TRANSVERSE SECTION OF SYCAMORE (× 15) showing conspicuous bands of terminal parenchyma.

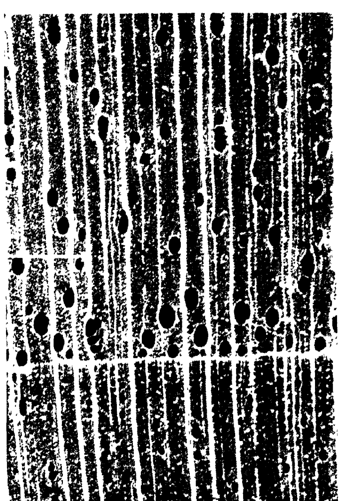


FIG. 28.—TRANSVERSE SECTION OF WALNUT (× 15) showing discontinuous lines of metatracheal parenchyma (the tangential series of white dots).

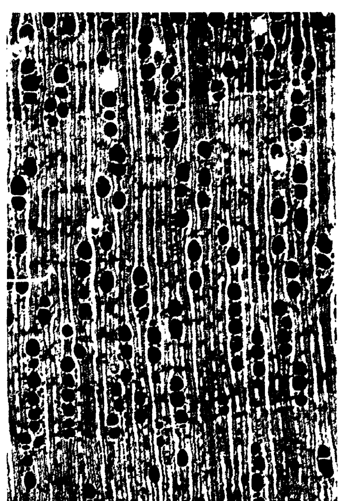


FIG. 29.—TRANSVERSE SECTION OF CHERRY MAHOGANY (× 15) showing broad bands of metatracheal parenchyma (the dark-coloured lines running across the rays).

Photos by L. A. Clinkard.

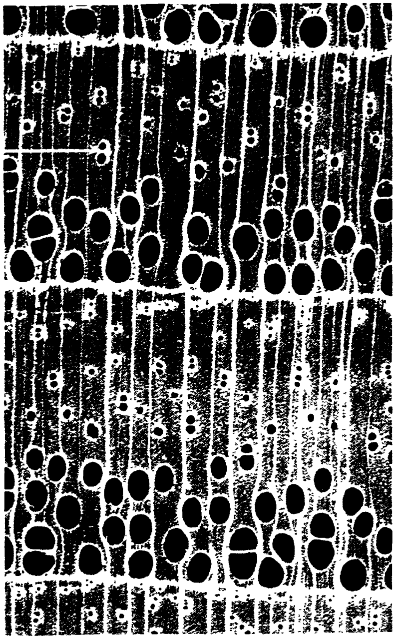


FIG. 30.—TRANSVERSE SECTION OF ASH ($\times 15$) showing vasicentric parenchyma (the white borders to the vessels).

FIG. 31.—TRANSVERSE SECTION OF MERBAU ($\times 15$) showing aliform parenchyma (the dark-coloured tissue surrounding the vessels).

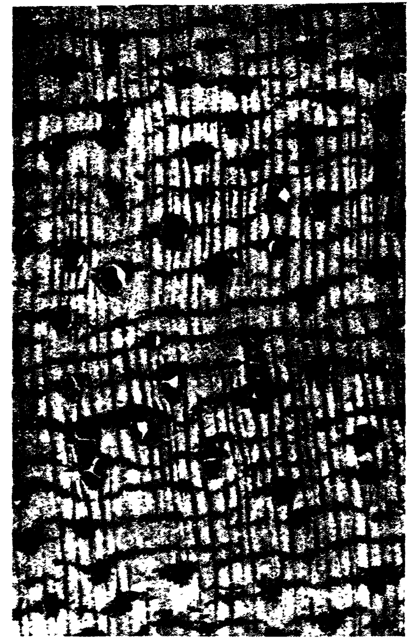
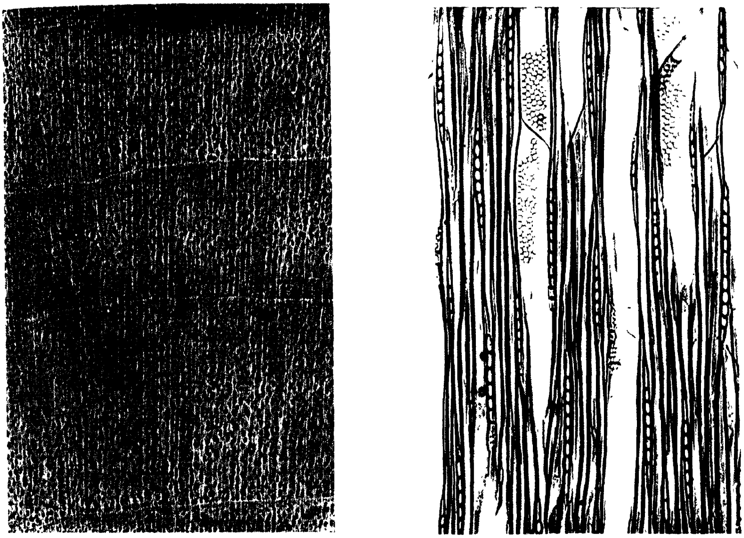


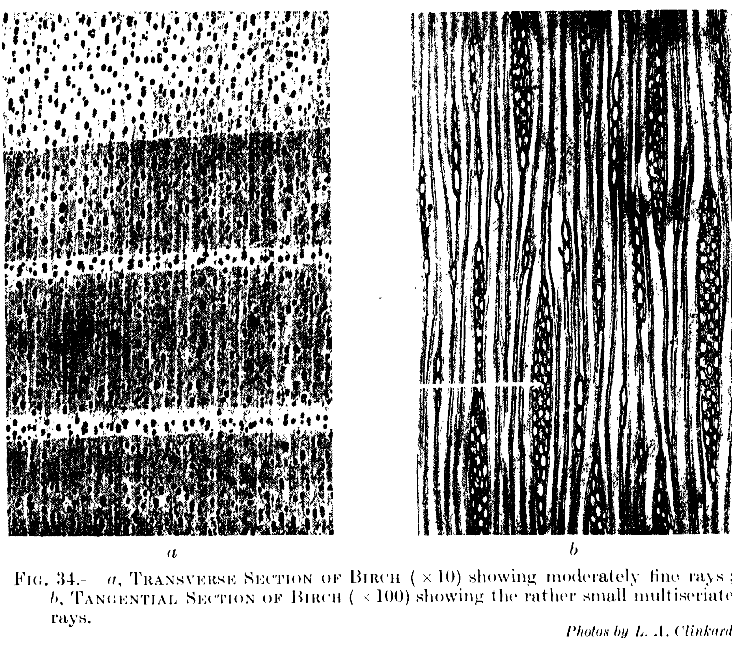
FIG. 32.—TRANSVERSE SECTION OF INDIAN ROSEWOOD ($\times 15$) showing confluent parenchyma (the dark-coloured bands joining up the vessels).

Photos by L. A. Clinkard



a *b*

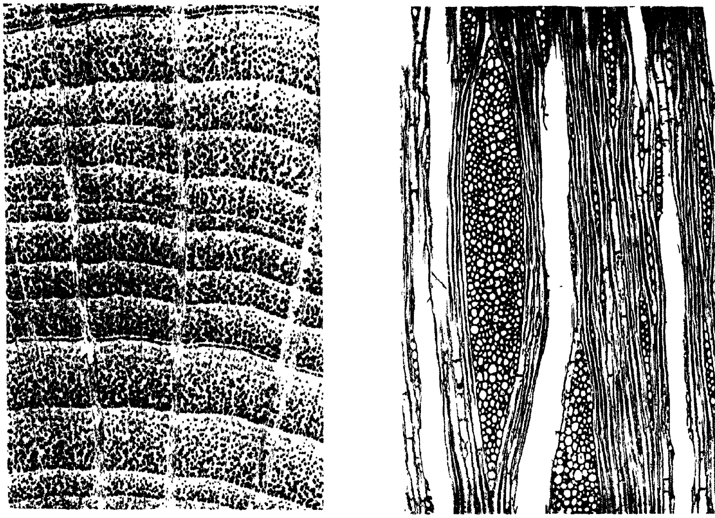
Fig. 33. *a*, Transverse Section of Willow (× 10) showing fine rays; *b*, Tangential Section of Willow (× 100) showing uniseriate rays.



a *b*

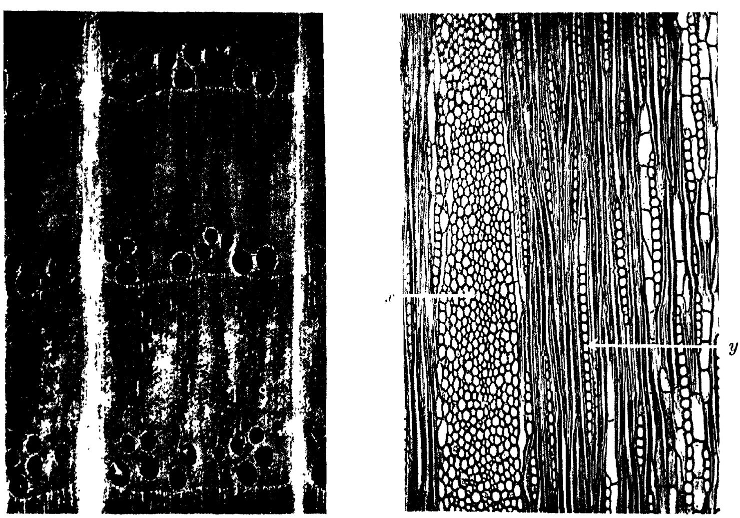
Fig. 34.—*a*, Transverse Section of Birch (× 10) showing moderately fine rays; *b*, Tangential Section of Birch (× 100) showing the rather small multiseriate rays.

Photos by L. A. Clinkard.



a *b*

FIG. 35.—*a*, TRANSVERSE SECTION OF BEECH (× 10) showing broad rays; *b*, TANGENTIAL SECTION OF BEECH (× 75) showing broad, multiseriate rays.



a *b*

FIG. 36.—*a*, TRANSVERSE SECTION OF OAK (× 10) showing rays of two distinct sizes (the fine uniseriate rays are indistinct); *b*, TANGENTIAL SECTION OF OAK (× 75) showing a part of a broad ray (*x*) and several uniseriate rays (*y*): note rays of intermediate size do not occur.

Photos by L. A. Clinkard.

as **ripple marks.** Ripple marks are a useful feature for distinguishing some timbers, *e.g.*, mansonia and the true Spanish and Honduras mahoganies (Fig. 38, *a* and *b*).

The individual ray cells may be either more or less similar in size and shape (in which case the rays are said to be **homogeneous,** Fig. 25 *a*), or distinctly variable (in which case the rays are **heterogeneous,** Fig. 25 *b*). The type of ray is a great help in identification, but in most cases it is not possible to determine whether the rays are homogeneous or heterogeneous without recourse to the microscope.

CRYSTALS AND DEPOSITS OF SILICA IN WOOD

The storage tissue of many timbers contains crystals, usually of calcium oxylate (Fig. 6, *a* and *b*). These may be confined, in different species, to the wood parenchyma or rays, or they may occur in both tissues. More rarely these cells may contain deposits of silica, *e.g.*, the ray cells of some kinds of white meranti and white seraya (Fig. 6 *c*). These substances may have an important bearing on the working qualities of particular timbers: an appreciable amount of silica in a wood necessitates the use of special saws and adjustment of cutting speeds.

RESIN CANALS OR GUM DUCTS

Normal "resin" canals or "**gum ducts**" are comparatively infrequent in hardwoods, although they are a constant feature of certain families, of which the most important commercially is the *Dipterocarpaceae*, *e.g.*, meranti, keruing, gurjun, apitong, and lauan. They may occur either as vertical canals in the wood, or horizontally in the rays, or more rarely, both vertically in the wood and horizontally in the rays, in the same species. The vertical canals may occur in tangential lines, producing the appearance of growth-ring boundaries (Fig. 39), or they may be distributed in short tangential series throughout the wood (Fig. 40).

"Resin" canals are produced as a result of wounding in many hardwoods. Such canals are said to be traumatic, and they may be recognized because they are invariably in tangential lines (Fig. 42). In some species traumatic canals are of sufficiently frequent occurrence to be regarded almost as a characteristic feature of the timber, *e.g.*, Nigerian walnut.

The contents of the canals may be black, yellow, or white. In the family *Dipterocarpaceae* they are most frequently white and, in consequence, when the canals are in tangential series they are often conspicuous to the naked eye on all surfaces.

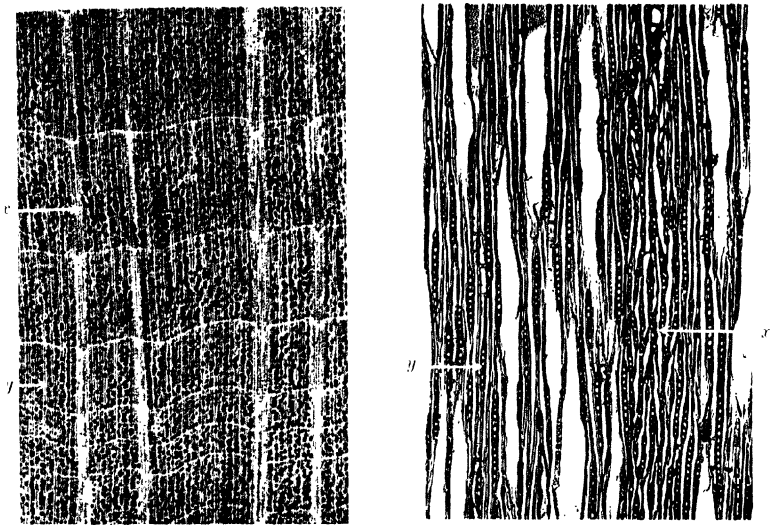
LATEX CANALS

Special cells or tubes, concerned with the storage of latex, occur in the ray tissue of certain timbers. They are usually invisible to the naked eye, but where they can be detected they are a helpful feature in identification. In a few timbers, *e.g.*, jelutong, mujua, specialized parenchymatous tissue, containing numerous **latex canals**, develops from leaf-traces and continues outwards during the subsequent growth of the bole; they are up to ½ in. high and lens-shaped in cross section (Fig. 43). As the leaf-traces occur in whorls the latex tissue is found in tangential series at intervals of 2 to 3 ft., disfiguring long lengths of timber.

INCLUDED PHLOEM

A few timbers contain strands or layers of phloem tissue included in the secondary xylem, as a result of the abnormal development of the cambium. This phloem tissue is known as **included phloem.** The zones extend up and down the tree, but they may be quite small in cross section, or several inches wide tangentially and up to ½ in. radially. Included phloem, being of different structure from normal wood, may behave differently in seasoning, and give rise to checks or splits.

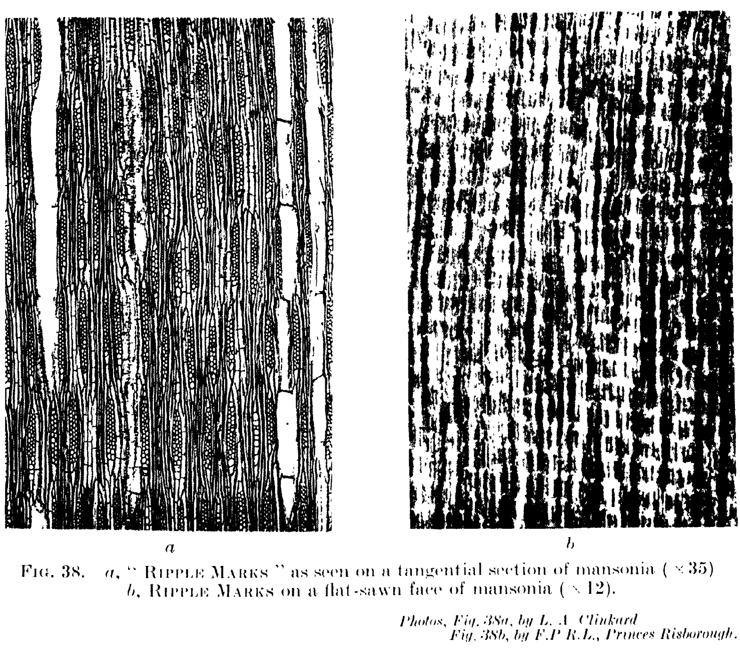
In the foregoing pages the units composing woody



a *b*

FIG. 37. *a*, TRANSVERSE SECTION OF ALDER (× 10) showing aggregate rays (*x*) and fine rays (*y*); *b*, TANGENTIAL SECTION OF ALDER (× 50) showing an aggregate ray and several uniseriate rays.

Photos by L. A. Clinkard.



a *b*

FIG. 38. *a*, "RIPPLE MARKS" as seen on a tangential section of mansonia (× 35) *b*, RIPPLE MARKS on a flat-sawn face of mansonia (× 12).

Photos, Fig. 38a, by L. A. Clinkard
Fig. 38b, by F.P R.L., Princes Risborough.

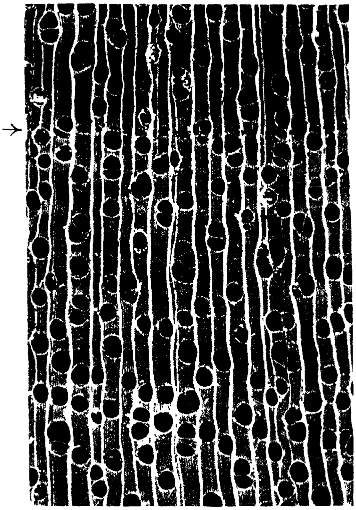


FIG. 39. TRANSVERSE SECTION OF MERANTI (× 10) showing a tangential line of vertical "resin" canals. Note the canals appear black in the figure because the "resin" is dissolved in the process of mounting the section.

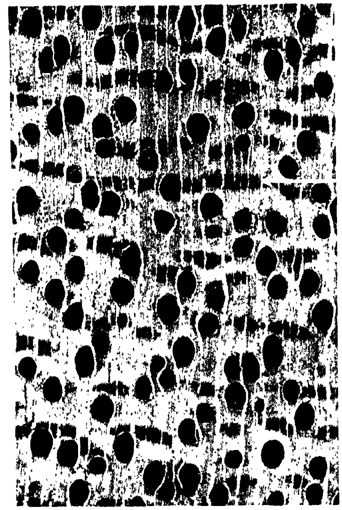


FIG. 40. TRANSVERSE SECTION OF KERUING (× 10) showing the short tangential series of vertical "resin" canals.

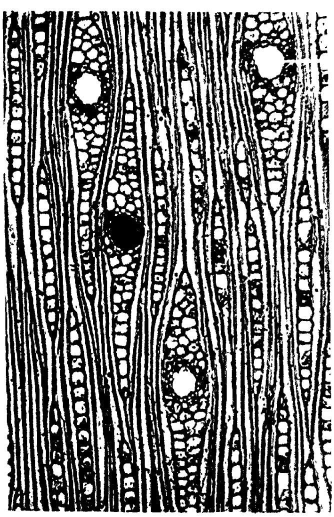


FIG. 41.—TANGENTIAL SECTION OF RENGAS (× 75) showing normal radial canals.

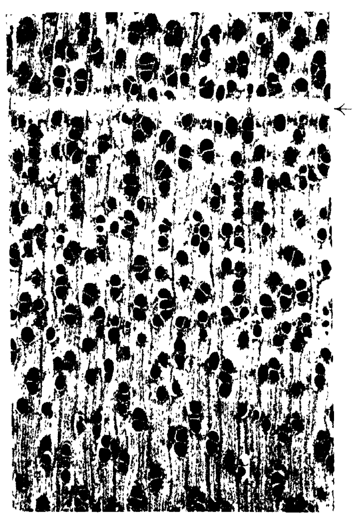


FIG. 42.—TRANSVERSE SECTION OF NIGERIAN WALNUT (× 10) showing traumatic "gum ducts."

Photos by L. A. Clinkard.

FIG. 43. TANGENTIAL FACE OF MUJUA BOARD showing a series of ribbons of parenchymatous tissue containing latex canals (natural size).

Photo by F P R.L., Princes Risborough.

structure have been discussed only in the detail necessary for a proper understanding of the properties and identification of wood. Readers who wish to go further into the subject are referred to such works as Record's *The Timbers of North America*, and standard textbooks on botany.

PART II

THE GROSS FEATURES OF WOOD

CHAPTER IV

GENERAL CHARACTERS

In Part I it has been shown how the structure of wood is the outcome of the requirements of the living tree. It remains to be seen how this structure determines the usefulness of timber to man. It has been stated that the kinds of cells, and their arrangement, chemical composition, and physical structure, determine the properties of wood. These factors also govern the details of the gross features such as colour, sapwood, heartwood, and growth rings, which are readily seen with the naked eye, and enable one to assess the quality of timber.

SAPWOOD AND HEARTWOOD

A striking feature of the majority of woods is the differentiation into sapwood and heartwood. Generally speaking sapwood is lighter in colour, less durable and, in the log, wetter than the heartwood.

It is usual to regard sapwood as inferior to heartwood, so that one of our first considerations is to examine how far the specification of timber free from sap is justified. That this is a point of considerable importance will be realized when it is seen how high is the percentage of sapwood in an average log. For example, a ring of 2 in. of sapwood is not exceptional, but this represents :

56 per cent.	of the	total	volume	in a log	12	in.	in diameter
30 per cent.	,,	,,	,,	,,	24	,,	,,
21 per cent.	,,	,,	,,	,,	36	,,	,,
16 per cent.	,,	,,	,,	,,	48	,,	,,

A width of only 1 in. in a small log 12 in. in diameter represents 31 per cent. of sapwood, and some tropical timbers have as much as 12 in. of sap, although this is admittedly exceptional. As a general rule, average-size commercial logs, with a normal amount of sapwood, may be expected to contain between 25 to 30 per cent. of sap, representing an appreciable waste if it is discarded.

The various properties of sapwood and heartwood are compared below:

Colour.—In some timbers there is no colour distinction between sapwood and heartwood, but in the majority the heartwood is more deeply coloured.

Weight.—There is usually no significant difference between the weight of sound sapwood and sound heartwood of the same moisture content.

Strength Properties.—Mechanical tests indicate that sapwood of the same moisture content and density as heartwood, and free of defects, is approximately equivalent in strength properties. The figures for sapwood are a little lower in some cases, but the differences are not of practical significance.

Durability.—The sapwood is rich in plant food material which is attractive to certain wood-rotting fungi and insects. Different timbers vary appreciably in this respect, and fungi and insects are selective in their hosts. For example, powder-post beetles must have starch, but they cannot attack softwoods or small-pored hardwoods because of the lack of facilities for egg-laying. The infiltrates of the heartwood, on the other hand, are frequently positively toxic to fungi and insects. In positions where wood is exposed to decay or insect attack sapwood is usually much less durable than heartwood of the same species.

Permeability.—The conducting tissue of wood usually undergoes modifications at the time of heartwood formation so that the free movement of liquids is interrupted.

As a consequence heartwood is not so easily impregnated with preservatives or dyes as is sapwood.

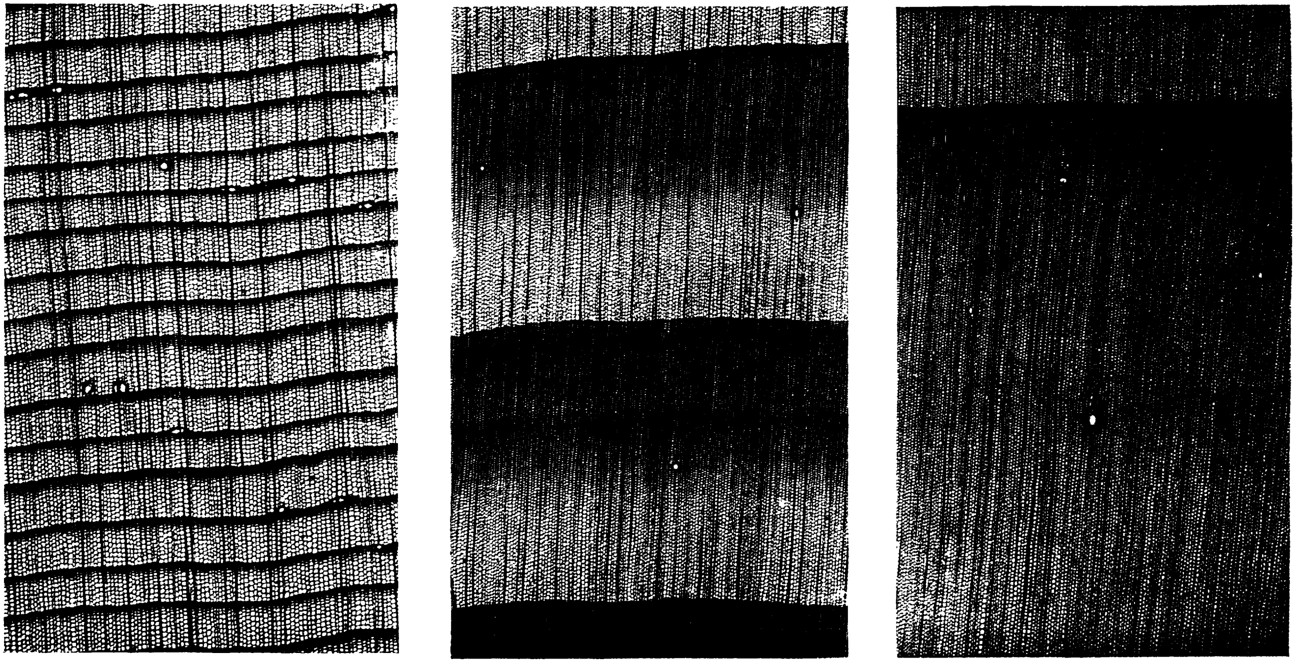
Where colour is of primary importance it is usually necessary to exclude sapwood, but the difficulty may sometimes be overcome by judicious staining. For some purposes, however, absence of colour is considered desirable, and in these circumstances the light colour of the sapwood is an advantage. Where colour is unimportant, durability is the controlling factor, and durability depends on the conditions under which the timber is to be used. For outdoor uses generally, *e.g.*, fencing, posts, gates, and railway sleepers, sapwood should be excluded unless the wood is treated with a preservative, in which case it may safely be retained. In well-ventilated, dry, internal situations, such as carcassing and joinery work generally, there is no objection to sapwood provided (1) that the timber is thoroughly well seasoned *before* it is installed, (2) that the site conditions cannot reasonably be expected to alter adversely *after* the timber is installed, and (3) that the timber is not one prone to powder-post beetle and borer attack, or that the risk of such attack is remote. In effect, in temperate regions the sapwood of softwood timbers can be retained in most indoor situations, but that of several hardwoods, *e.g.*, oak, mahogany, and walnut, should be excluded, as it is susceptible to powder-post beetles. In the tropics the risk of wood-borer infection of several types is so much greater that sapwood should always be excluded.

Although sapwood may be used in certain circumstances, it must not be overlooked that its presence is a potential source of danger should the site conditions change at any time, and this fact must be borne in mind when drawing up a specification. For example, there is a greater risk that built-in wall plates and ground-floor, basement, and roofing timbers, may be exposed to damp than there is that first floor and ceiling joists will be, and damp conditions render wood liable to fungal attack. It would, therefore, be reasonable to allow sapwood in positions where risks of attack are

small, and to exclude it where the likelihood of infection is considerable. It will often be found impossible in practice to obtain softwood timber entirely free of sap so that the problem resolves itself into paying proper attention to "site" conditions. Damp-proof courses and air bricks provide the means for maintaining good internal conditions, and it is imperative that they should be given proper attention. It is not unusual, for example, to find ground-line air bricks blocked-up, or for flowerbeds to be raised above the damp-proof course: in such circumstances the protective measures are rendered ineffective. Another cause of damp interiors is neglected pointing, and this may lead to decay of the timber inside the building.

As sapwood is more readily impregnated with preservatives than heartwood it should be retained whenever the material is to be properly impregnated, particularly if the timber is in the round, or roughly squared, and is completely encircled by sapwood. If the application of preservatives is confined to brush coating the ends of beams, joists, or posts, sapwood pieces should not, of course, be selected in preference to timber free from sap.

In certain other circumstances, *e.g.*, sports goods, tool handles, shuttles, spools, and bobbins, sapwood is sometimes preferred to heartwood, but in most cases there is either no justification for the preference, or the heartwood of the timbers used for such purposes does not differ in colour from the sapwood. For example, there was a preference in America for the sapwood of hickory to the exclusion of the heartwood, but exhaustive tests by the Forest Products Laboratory, Madison, show that the heartwood is equally suitable for all purposes for which the sapwood was preferred. Again, the favourite timbers for shuttles, spools, and bobbins (persimmon, cornel, and boxwood), have little or no heartwood, or the heartwood is the same colour as the sapwood. In one or two tropical timbers the sapwood is distinctly lighter in weight than the heartwood, and for this reason is preferred for tool handles, because the strength properties of the lighter timber are more than adequate for the purpose. Sapwood is, of course, freer from such defects as knots and shakes, but this



a *b* *c*

FIG. 44.—TRANSVERSE SECTIONS OF DOUGLAS FIR (12): *a*, SLOW GROWN (54 rings per inch); *b*, MEDIUM-SLOW GROWN (8 rings per inch); *c*, FAST GROWN (under 3 rings per inch).

Photos by L. A. Clinkard.

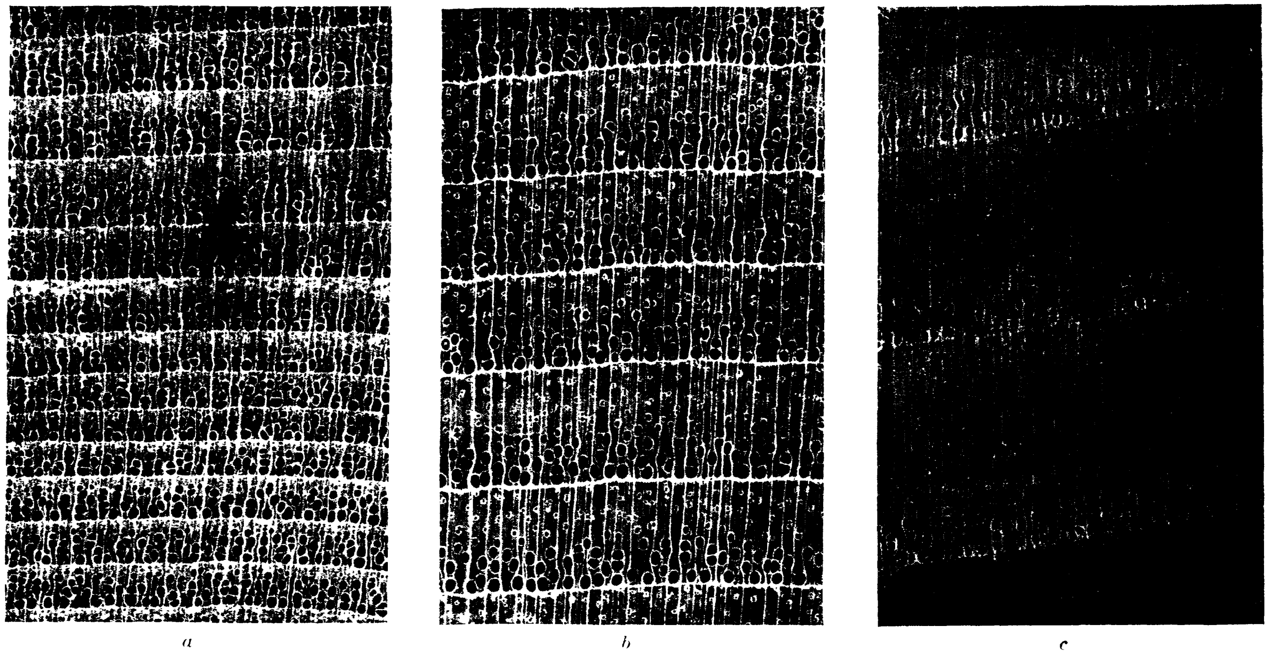


FIG. 45.—TRANSVERSE SECTIONS OF ASH (× 7): *a*, SLOW GROWN (40 rings per inch); *b*, MEDIUM-SLOW GROWN (19 rings per inch); *c*, FAST GROWN (9 rings per inch).

Photos by L. A. Clinkard.

advantage is minimized in comparison with the outer heartwood of large-sized trees.

GROWTH RINGS OR LAYERS

The second gross feature to be considered is the presence or absence of growth rings or layers. These, it has been explained, occur in timber grown in regions with distinct seasonal climates, in which a growing period alternates with a resting state, and where the wood laid down at one period of the growing season differs from that produced later in the season. The character of the growth ring is sometimes useful in identifying a timber, and is often of value in assessing the quality of a piece of wood.

The width of rings, or the number of rings per inch of radius, is a measure of the rapidity of growth, and is some indication of the strength properties of wood. In softwoods and the ring-porous hardwoods, variations in ring width are associated with variations in the proportion of late to early wood (Figs. 44 and 45). In the diffuse-porous woods, in which the wood produced in one growing season is not differentiated into early and late wood, variations in ring width are associated with variations in porosity. In all three types of wood extremely narrow and extremely broad rings are an indication of exceptionally weak timber; probably in all species there is an optimum rate of growth for the production of the strongest timber, but the rate differs with the species. In softwoods this optimum is about 7 to 20 rings per inch, and within these limits the *narrower* the ring the *narrower* is the band of early wood, and, consequently, the *higher* is the proportion of late wood. In ring-porous woods the optimum is roughly 7 to 15 rings per inch, and within these limits the *wider* the ring the *wider* the band of late wood, and, consequently, the *higher* is the proportion of late wood. It may be recalled that the late wood is composed largely of strengthening material and, therefore, the higher the proportion of late wood the stronger the timber. It follows that

within the optimum limits for the species, the narrower the rings of softwoods and the wider the rings of ring-porous hardwoods the stronger the timber.

The weakness of the very slowly grown softwoods and ring-porous hardwoods is accounted for by the very narrow zones of late wood which their rings contain. The weakness of rapidly grown softwoods, on the other hand, is accounted for by the very wide bands of early wood. In hardwoods grown faster than the optimum limits, however, although there is an increase in the proportion of late wood, the individual fibres are abnormally thin walled, and the timber is, in consequence, weaker than less rapidly grown material in which the late wood fibres have thicker walls.

Width of rings, as a criterion of strength, is at best a compromise, but it is a factor that can be determined in the timber yard or workshop. For example, the writer classified a stock of ash tool handles into grades on a ring-width basis and, by imposing an arbitrary maximum number of rings per inch of radius, eliminated practically all the inferior timber. On the other hand, mechanical tests showed that the arbitrary classification excluded a considerable proportion of good timber. Had weight been utilized as a second factor a more accurate estimate of quality would have been realized. The value of the rings per inch classification depends on whether, in practice, the acceptance of a certain amount of inferior timber would be more economical than paying the higher price resulting from the imposition of too strict a specification, and this is a point that must be settled separately for each case.

Strength properties are not the only factors that determine the merits of a timber : for some purposes working qualities are of equal or greater importance. In such circumstances, timber produced under other than the optimum rate of growth conditions for strength may be superior to that produced under the optimum conditions. For example, mildness of character is associated with narrow-ringed material. The mildest softwood timber is that from northern Europe and the higher altitudes of central Europe, and the rings may well

FIG. 46.—CROSS SECTION OF SPRUCE LOG showing compression wood (the dark, wide-ringed portion shown in the lower part of the section).

Photo by U.S. Forest Products Laboratory.

exceed 20 to the inch, but such timber is unsurpassed for joinery purposes. In the same way, the milder, slower-grown, and consequently narrower ringed " Austrian " oak is preferred for flooring, panelling, etc., to the faster grown, wider-ringed, and stronger English oak. The English oak is, however, better for constructional work.

COMPRESSION WOOD

In softwoods a special type of tissue, known as **compression wood,** is developed on the under (compression) side of branches and the lower sides of leaning stems. The outstanding feature of this type of wood is its abnormally high longitudinal shrinkage. Whereas normal wood shrinks 0·1 to 0·2 per cent. from the green to the oven dry condition, compression wood may shrink as much as 5·78 per cent., and is commonly 0·3 to 1·0 per cent.[1] In consequence, boards and planks containing compression wood are liable to bow in seasoning. The abnormal wood is also exceptionally dense, but the extra weight is not accompanied by equivalent increase in strength ; in particular compression wood has relatively low bending strength and lacks toughness. The changed properties may be attributed to abnormally high lignin content, and for this reason compression wood is not suitable for chemical paper pulp, and its lack of toughness is equally objectionable in mechanical pulp.

In most species compression wood may be recognized by its relatively dark red-brown colour, and by the lack of contrast in colour between the early and late wood (Fig. 46). In boards and planks the abnormal wood frequently occurs in streaks running the length of the timber.

GRAIN, TEXTURE, AND FIGURE

Grain and texture should be used to refer to two quite distinct characters of wood, but more often than not they are

[1] Figures from " The Longitudinal Shrinkage of Wood ", by A. Koehler, in *Trans. Am. Soc. Mech. Engineers*, Jan.–April 1931, vol. 53, No. 5.

confused in everyday use. An attempt has been made by timber research laboratories to standardize the use of the terms, restricting each to a single feature. It is proposed that **grain** shall refer to the direction of the fibres, relative to the axis of the tree or the longitudinal edges of individual pieces of timber, and that **texture** shall apply to the relative size, and the amount of variation in size, of the cells.

Figure refers to the pattern produced on longitudinal surfaces of wood, as a result of the arrangement of the different tissues, and the nature of the grain.

Before describing the different types of grain, it will be as well to discuss the incorrect uses of this term. These fall under several heads, *e.g.*, those describing the manner of sawing, those correctly pertaining to texture, and those referring to width of growth rings. Of the first, we have quarter, edge, vertical, and comb grain, referring to timber which is cut parallel to the rays; for such timber the term " **quarter-sawn** " is proposed. Timber cut at right angles to the rays, should be described as **flat-** (or back-) **sawn** and not as " flat grain ". In hardwoods " coarse " and " fine grain " are frequently applied to characteristics which depend on the size of the elements, and, therefore, are more correctly described as **texture**; oak, for example, should be described as coarse textured and not coarse grained. In softwoods, on the other hand, coarse and fine grained are often used to describe the width of growth rings; the former to wood with broad rings, and the latter to wood with narrow rings. Here the feature is neither grain nor texture, and is better described by the terms **wide-** and **narrow-ringed** or fast- and slow-grown.

" Even " and " uneven grain " have been used to distinguish regularity and irregularity in the width of growth rings. As this character is neither dependent on the direction of the fibres nor on the size of cells, but on the rate of growth, it is inaccurate to refer to it as either *grain* or *texture*, and a much clearer idea is given by employing the phrase " **growth rings regular** (or **irregular**) **in width** ".

FIG. 47. – FLAT-SAWN RED DEAL.

By courtesy of E. H. B. Boulton, Esq.

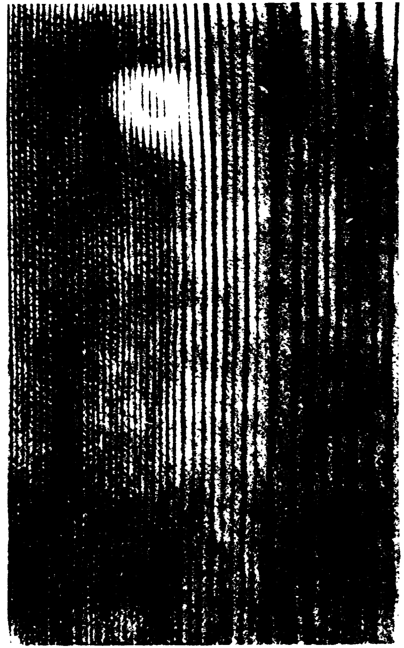


FIG. 48. QUARTER-SAWN DOUGLAS FIR ("EDGE GRAIN").

By courtesy of the Editor of "Wood"

FIG. 49.— ROTARY-CUT VENEER OF DOUGLAS FIR.

Photo by F.P.R.L., Princes Risborough, sample lent by the Editor of "Wood".

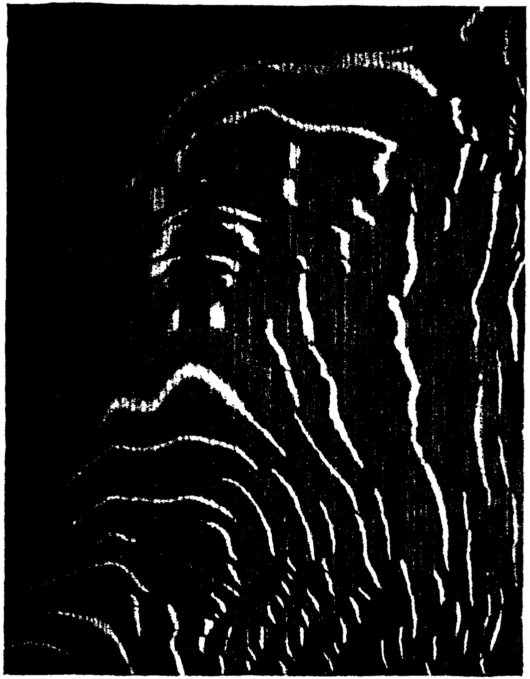


FIG. 50.—SILVER FIGURE IN QUARTER-SAWN OAK.

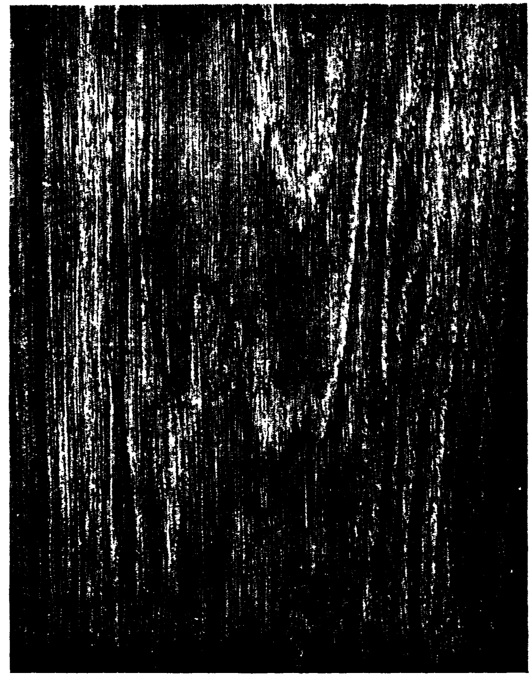


FIG. 51.—FLAT-SAWN OAK.

Photos by F. P. R. L., Princes Risborough.

Timber that breaks with a short, brittle fracture is frequently described as *short in the grain.* The description is inapt as the failure has nothing to do with the direction of the fibres but with their brittleness. This may be an inherent property of the species, or it may be caused by such factors as fungal decay, " spongy heart ", exceptionally low density (for the species), compression wood, or even maltreatment in seasoning (usually too rapid drying in a kiln at a high temperature and too low humidity).

" Grain " is sometimes applied to describe the figure of a timber: *silver grain*, for example, refers to the appearance of certain timbers cut on the quarter and is only indirectly connected with the direction of the cells.

Grain.—Using the restricted meaning, six types of grain may be distinguished. **Straight grain** explains itself. In straight-grained timber the fibres and other elements are more or less parallel to the vertical axis of the tree. In addition to being a contributory factor in strength, straight-grained timber makes for ease of milling and reduces waste. On the other hand, it does not give rise to ornamental figure.

Irregular Grain.—Timber in which the fibres are at varying, and irregular, inclinations to the vertical axis in the log, is said to have irregular grain. It is frequently restricted to limited areas in the region of knots or swollen butts. It is a very common defect and, when excessive, seriously reduces strength, besides accentuating difficulties in milling. Irregular grain, however, often gives an attractive figure. Very pronounced irregularities in the direction of the fibres, resulting from knoll-like elevations in the annual rings, produce **blister figure** (Fig. 52). The valuable and attractive **bird's eye figure** (resulting from conical depressions as opposed to elevations of blister figure) seen on the finished tangential surfaces of selected material of a few species, *e.g.*, maple, although due to the alignment of the fibres, is held to be the result of temporary injury to the cambium (Fig. 53).

Diagonal grain is a milling defect, and is due to otherwise straight-grained timber being cut so that the fibres do

not run parallel with the axis of the board or plank ; such timber is, of course, weaker than that properly sawn.

Spiral grain is produced when the fibres follow a spiral course in the living tree. The twist may be left- or right-handed. The inclination of the fibres may vary at different heights in the trunk, and at any one height the inclination may vary at different distances from the pith. The cause of spiral grain is not definitely known, but there is evidence that it is an hereditary character of individual trees. Although not always readily visible spiral grain may often be detected from the direction of the surface seasoning checks. Spiral grain reduces the strength of timber and in aeroplane propellers, for example, is a very serious defect.

Interlocked grain, or **interlocked fibre** as it is often called, results from the fibres of successive growth layers being inclined in opposite directions, producing on quarter-sawn surfaces the familiar figure known as **ribbon** or **stripe figure** (Fig. 55). The interlocked grain is sometimes irregular and causes a breaking of the stripe which gives rise to **roe figure** (Fig. 56). Interlocked grain is relatively uncommon in temperate woods but it is a characteristic feature of most tropical timbers. As far as is known, interlocked grain does not appreciably affect the strength of timber, but it may cause serious twisting during seasoning and, if pronounced, makes the wood difficult to split radially (Fig. 58). There is also the added disadvantage that such timber " picks up ", particularly when being sawn on the quarter, leaving a very rough finish. A reasonably smooth surface can be obtained, however, with modern machines, employing a suitable cutting angle and rate of feed.

Wavy Grain.—When the direction of the fibres is constantly changing, so that a line drawn parallel with them appears as a wavy line on a longitudinal surface the grain is said to be **wavy**. This type of grain gives rise to a series of diagonal, or more or less horizontal, darker or lighter stripes on longitudinal surfaces, owing to variations in the reflection of light from the surface of the fibres : this is called **fiddle-**

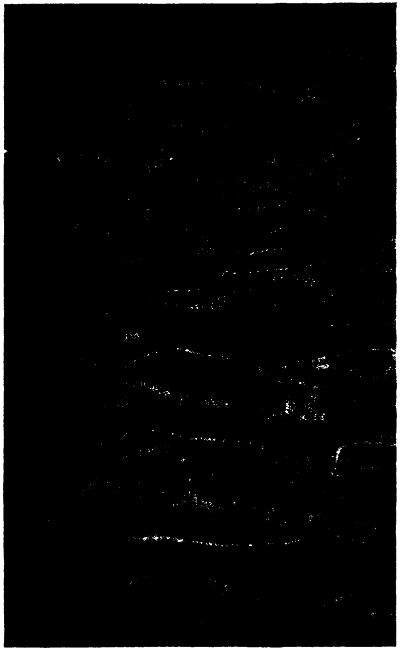


Fig. 52.—Blister Figure in Pacific Maple.

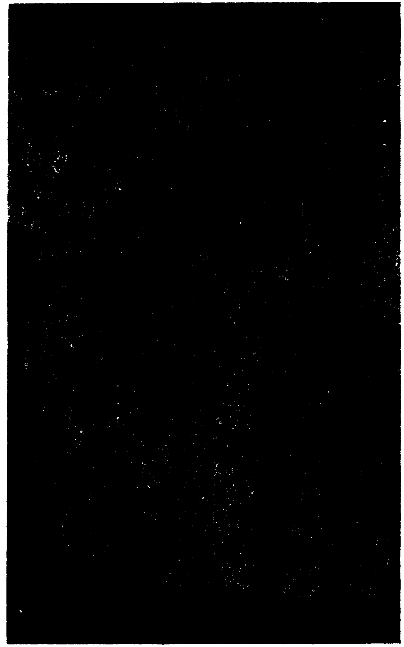


Fig. 53.—Bird's-eye Figure in Maple.

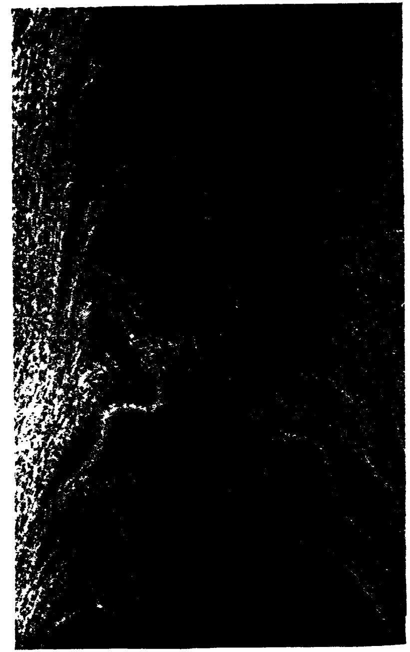


Fig. 54.—Curl Figure in Spanish Mahogany.

Photos by F.P.R.L., Princes Risborough; veneers lent by Messrs. John Wright (Veneers) & Sons

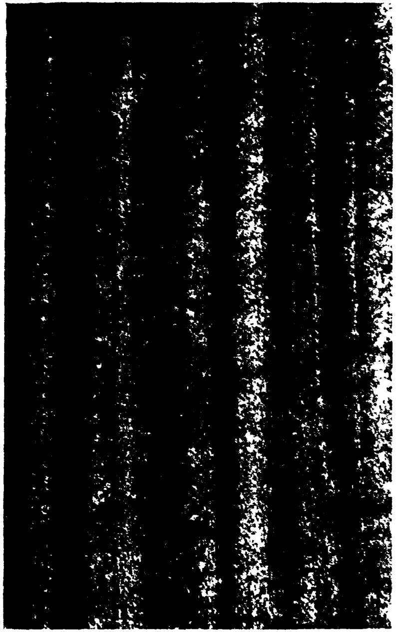


FIG. 55.—STRIPE OR RIBBON FIGURE IN AFRICAN MAHOGANY.

By courtesy of E. H. B. Boulton, Esq.

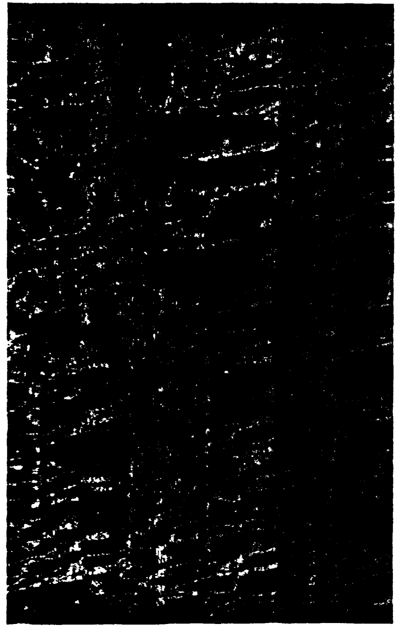


FIG. 56.—ROE FIGURE IN MAHOGANY.

Photo by F.P.R.L., Princes Risborough; veneer lent by Messrs. John Wright (Veneers) & Sons.

FIG. 57.—FIDDLE-BACK FIGURE IN WALNUT.

Photo by F.P.R.L., Princes Risborough; veneer lent by Messrs. John Wright (Veneers) & Sons.

back figure (Fig. 57). Wood with wavy grain presents a corrugated surface, as shown in Fig. 59, when split. The importance of this type of grain lies in its decorative value, and any reductions in strength are of no consequence.

Texture.—Just as it was necessary to employ qualifying

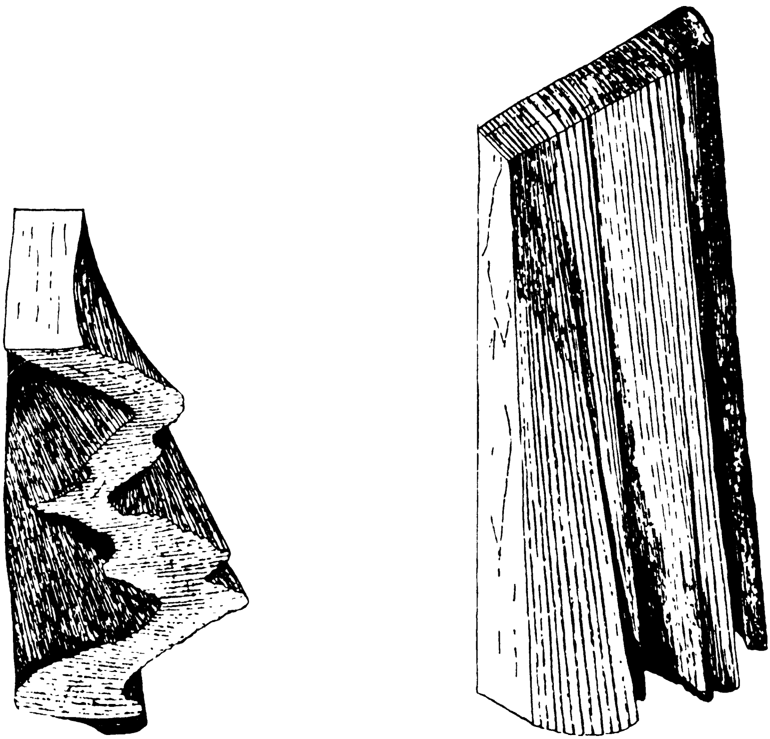


FIG. 58.—INTERLOCKED FIBRES as seen on a split radial surface.
By courtesy of Canadian Forest Service

adjectives to describe the different types of grain, so is it with texture, and we have the terms coarse, fine, even, and uneven texture. The differentiation between coarse and fine texture is made on the dimensions of the pores, and the width and abundance of the rays. Timbers in which the pores are large, or the rays broad, are said to be of **coarse texture,** but

when the pores are small, and the rays narrow, the timber is of **fine texture.** Many intermediate grades of texture are met with, and some such classification as the following will be found useful :—*very fine*, *e.g.*, box ; *fine*, *e.g.*, sycamore, beech ; *medium*, *e.g.*, birch ; *moderately coarse*, *e.g.*, walnut, mahogany ; *coarse*, *e.g.*, oak. Strictly speaking all softwoods are fine, or at most only moderately coarse textured, as their cells are all of relatively small diameter.

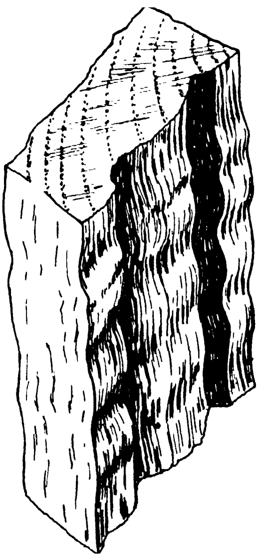


FIG. 59.—WAVY GRAIN as seen on a split surface.

The texture of softwoods is influenced by the alternation of the zones of early and late wood. When the contrast between the zones is strongly marked the wood may be said to be of **uneven texture**, *e.g.*, pitch pine, Douglas fir, larch ; when there is little or no contrast the wood may be said to be of **even texture**, *e.g.*, white pine, true firs, spruce. In this sense the terms may also be applied to hardwoods ; ring-porous woods are uneven in texture, but diffuse-porous woods are usually even in texture.

Figure.—Several different types of figure have been mentioned in the discussion on grain, but many more than these are recognized in trade terminology. Those recorded are, however, the principle types, and other kinds of figure are merely modifications of the basic types. For example, **ram's horn** is a special form of wavy grain in which the waves are comparatively short, so that the resulting horizontal stripes are narrow and close together. Curls which resemble ostrich feathers are called **feather curl** as in crotch mahogany (Fig. 54), and so on.

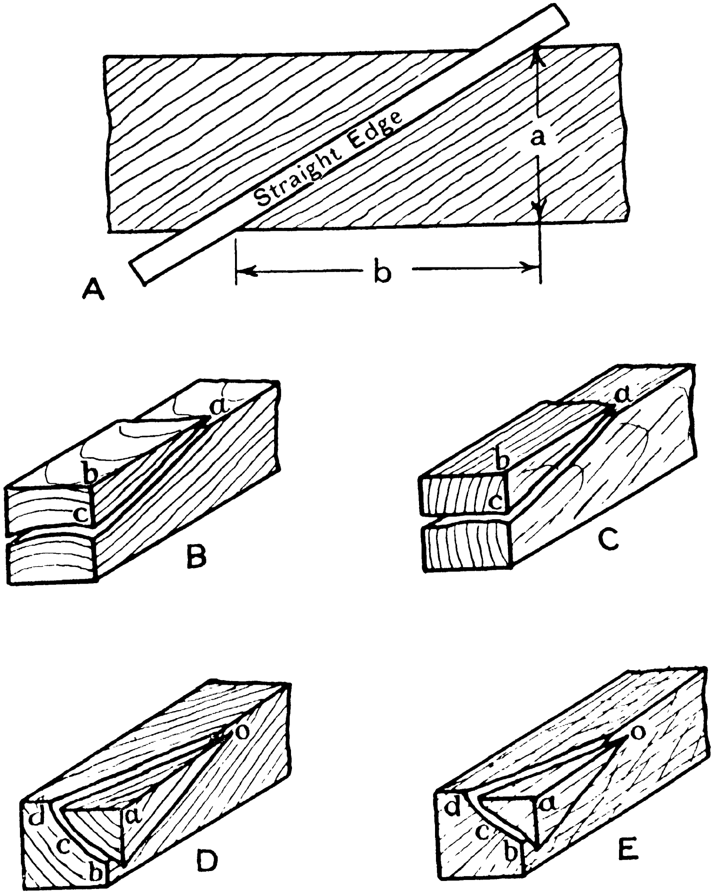


FIG. 60.—MEASUREMENT OF THE SLOPE OF THE GRAIN. A, B, and C, measurement of slope when the timber is truly quarter- or flat-sawn: slope $= \frac{a}{b}$ in A, and $\frac{bc}{ab}$ in B and C. D and E, measurement of slope when the timber is not truly quarter- or flat-sawn: slope $= \frac{ac}{ao}$, *ac* being perpendicular to the line *bcd* along a growth ring in D, and *bcd* being perpendicular to a growth ring in E.

By courtesy of the Commonwealth of Australia Department of Scientific and Industrial Research.

THE INFLUENCE OF THE DIRECTION OF THE GRAIN ON THE UTILIZATION OF WOOD

When the strength of timber is the primary consideration it is usual to specify that it shall be straight grained. The importance of this specification will be seen when it is realized that there is a reduction of about 4 per cent. in bending strength when the slope of the grain is 1 in 25; with a slope of 1 in 20 the reduction is 7 per cent.; with 1 in 15, 11 per cent.; with 1 in 10, 19 per cent.; and with 1 in 5, 45 per cent. The stiffness of a beam is also reduced by sloping grain, but to a less degree; the corresponding reduction in strength for the same variations of slope being respectively 3, 4, 6, 11, and 33 per cent. The percentage reductions in strength and stiffness vary somewhat with different species, but the figures quoted give an indication of the general trend. In consequence, it is recommended [1] that a slope of greater than 1 in 15 should not be permitted in beams; in flooring and in the smaller sizes of joists and rafters, on the other hand, where stiffness is generally of more importance than bending strength, a slope of 1 in 10 is usually permissible. Timber for tool handles and sports goods needs more careful selection, since a slope of only 1 in 25 causes a reduction of 9 per cent. in impact bending (shock-resisting abilities). Timber for such purposes should be as nearly straight-grained as possible, and in no circumstances should the slope exceed 1 in 25. Even greater care is necessary in the selection of timber that is to be steam-bent, as satisfactory bends cannot be made from other than straight-grained timber. The requirements of wood for barrel staves for tight cooperage illustrate another aspect of the importance of grain direction. Where the grain slopes from the inside to the outside of the cask there is a likelihood of the contents seeping through the staves, hence,

[1] Cross, diagonal, and spiral grain in timber: Commonwealth of Australia, Council for Sci. Ind. Research, Division of Forest Products, *Trade Circular No. 13*, 1933.

straightness of grain is an essential quality in timber for this purpose.

It is not always easy to recognize that a piece of timber is not straight-grained, particularly on the flat-sawn faces of timber with conspicuous growth rings, or on any face of timber without growth rings. A useful indication is given by the **vessel line,**[1] gum veins, resin ducts, and seasoning checks. In the absence of these features, and when it is impracticable to split the wood, the direction of the grain may be detected by raising a few fibres with the point of a pen knife, or alternatively by noting the spread of an ink spot.

COLOUR

From a practical viewpoint colour is of importance because it may enhance or detract from the decorative value of timber. Ebony, sycamore, mahogany, and walnut, are notable instances in which the use of timbers has to some extent been determined by their colour or lack of colour.

We have seen that colour is due largely to various infiltrates in the cell wall. Some of the infiltrates in certain timbers, *e.g.*, logwood, are extracted for use as dyes. Some undergo changes when timber is exposed to light, air, or heat, with the result that many timbers darken with age, and others fade. Mahogany fades under strong sunlight, but darkens in moderate light ; grey sycamore turns green in daylight, but not in artificial light. Several timbers, *e.g.*, teak, Borneo white seraya, exhibit quite a range of colour when freshly planed, but after a short exposure to daylight the colours even out considerably.

The moist heat employed during kiln seasoning darkens many woods, so much so that some are steamed purposely to alter the colour, *e.g.*, beech, walnut sapwood. Colour changes are also affected by chemical means, *e.g.*, liming lightens the colour and fuming darkens it, often removing the pink or red shades.

[1] The vessels as seen on longitudinal surfaces.

In an earlier section it has been mentioned that woods with a high tannin content are often very durable. These woods, oak, western red cedar, and gurjun, for instance, all develop unsightly dark stains if they are allowed to come in contact with iron under moist conditions.

ODOUR AND TASTE

Many timbers have a characteristic odour which is apparent when they are worked in a fairly fresh condition, but which usually disappears as the woods dry out. Perhaps the most outstanding examples are the characteristic resinous odour of the pines, the spicy aroma of sandalwood and cigar box cedar, and the camphor-like odour of Formosan camphor wood. Certain Australian timbers of the *Acacia* group possess an odour not unlike violets, coachwood is reminiscent of new-mown hay, West Indian satinwood of coconut oil, and Australian walnut has an objectionable fœtid odour which disappears as the wood dries.

The taste of wood is closely related to odour, and is probably due to the same constituents. Both properties influence the utilization of timber : the construction of food containers is limited to woods without pronounced odour or taste, as it is undesirable that any odour or taste should be imparted to the food itself ; the flavour of tobacco, on the other hand, is supposed to be improved when stored in Honduras cedar boxes ; and camphor wood is used for clothes chests in the East because it is reputed to repel insect pests.

IRRITANTS

The infiltrates and cell contents of some timbers have an irritating effect, which is manifest when the timber is worked. Sneezewood derives its name from the fact that the fine sawdust dust causes violent sneezing. Other timbers, *e.g.*, rengas and several of the *Anacardiaceae*, may cause dermatitis when green timber is handled.

LUSTRE

Lustre depends on the ability of the cell walls to reflect light. Some timbers possess this property in a high degree, *e.g.*, East Indian satinwood, lauan, but others are comparatively dull, *e.g.*, hornbeam. As a general rule, quarter-sawn surfaces are more lustrous than flat-sawn, and if stripe or ribbon figure is present this figure is considerably enhanced in timbers possessing a natural lustre. Although lustre is an asset in a cabinet timber, from a practical viewpoint the capacity for taking a good polish is quite as important, and the two do not necessarily go hand in hand.

CHAPTER V

THE IDENTIFICATION OF TIMBERS

THE PROBLEM

THE identification of timbers may appear, at first sight, a comparatively simple matter, but when it is realized that there are over 20,000 woody species in the world it will be appreciated that in some cases correct identification may be exceedingly difficult. Actually it is not always possible to arrive at the correct specific name from the examination of a single sample of wood, although it is usually possible to narrow down the identification to a group of related species, and this is sufficient for most practical purposes. Moreover, although there are so many species which produce woody stems, only a small proportion grow to timber size. At the same time, the number of species producing commercial timber runs into some hundreds, and the similarity between timbers of distinct species is often very close. The characters available for distinguishing woods are limited, and identification should be based on an examination of features that are known to be reliable.

THE PROCEDURE

The average timber user handles relatively few timbers and can usually recognize those with which he is familiar by a cursory glance; he is not, however, in a position to name timbers with which he is not familiar. On the other hand, it is often possible to arrive at the identity of an unfamiliar timber by a process of elimination along certain well-established lines.

The apparatus required for identifying timbers may include a high-power microscope and the complete paraphernalia of a laboratory devoted to the study of wood, but for most practical purposes a sharp pen-knife and a small pocket-lens, times ten magnification, are all that is necessary. The first step is to prepare a small area of end surface by making a clean cut with the knife. The importance of using a really sharp knife and obtaining an absolutely clean-cut end surface cannot be overstressed. A blunt knife simply obscures structural details and a notched edge produces scratches which may be mistaken for rays or lines of parenchyma. From quite a small area it is possible to see a considerable amount of detail with the aid of a lens that is not visible on a rough surface with the naked eye. After the end surface is prepared, the subsequent procedure depends on several circumstances, and only general principles can be discussed here.

In every case the first point to decide is whether vessels are present or not; this settles to which of the two main classes of timber (hardwoods or softwoods) the sample belongs. Next, the type of growth rings, or their absence, and then the presence or absence of resin canals are helpful features. The examination of a sample for these three features alone narrows the range appreciably. Other features, such as the type of rays, the distribution of the parenchyma, weight, hardness, and colour, are used in turn.

The procedure outlined above is the basis of all **keys** to the identification of timbers. Keys consist of successive pairs of mutually exclusive conditions, so arranged that by a process of elimination one is led step by step to the identity of the specimen. The following example illustrates the usual method of key construction:

(1) Vessels absent . . . . (2)
(1) Vessels present . . . . (x)
    (2) Resin canals present . . . . (3)
    (2) Resin canals absent . . . . (y)

(3) Latewood abruptly differentiated from early wood........................ (4)
(3) Latewood not differentiated from early wood............................ (w)

(x) Wood ring porous........................... (u)
(x) Wood diffuse porous......................... (z)
(u) Broad rays present....................... Oak
(u) Broad rays absent........................ (v)
(v)................
(v)................

In using this key one takes the first pair of conditions. If vessels are absent from the specimen under consideration one proceeds to the second pair and decides whether resin canals are present or absent and so on. If vessels are present one proceeds to question " x " to decide whether the wood is ring porous or diffuse porous, and so to condition u or z.

Timbers are so numerous, and the differences between them are so small, that it is impossible to construct a key to embrace all the timbers in the world. Several good keys exist which are restricted to the timbers of particular countries or localities. For example, Chalk and Rendle's key to British hardwoods,[1] Record's key to North American timbers,[2] Dadswell's keys to Australian timbers,[3] and Brown's key to Indian timbers,[4] are excellent for the timbers they embrace.

The successful use of keys necessitates some experience in the examination of small samples of wood, and this can only be obtained by practice. Readers who are anxious to be in a position to identify any but the few common timbers in everyday use would be well advised to make their own keys from a study of a collection of authentic samples of timbers.

[1] *British Hardwoods*, Forest Products Research Bull. No. 3, H.M. Stationery Office.

[2] *The Identification of the Timbers of Temperate North American Timbers*, by S. J. Record. John Wiley & Sons, 1934.

[3] *Bulls*. Nos. 67, 78, and 90, Council for Sci. Ind. Research, Commonwealth of Australia, Melbourne.

[4] *An Elementary Manual of Indian Wood Technology*, by H. P. Brown. Calcutta, Gov. India Central Publ. Branch, 1925.

PART III

THE PROPERTIES OF WOOD

CHAPTER VI

THE WEIGHT OF WOOD

IN Part II we discussed certain characters of wood, visible to the naked eye, which in some measure determine its usefulness and which are a guide to identification. In this chapter we will consider another character, namely the weight or **density**, which is the best single criterion of the strength of wood. As a general rule strength is roughly proportional to density so that heavy timbers are, on the average, stronger than lighter ones.

It is usual to speak of the weight of wood in terms of a standard volume and this figure is called the **density.** In this country the density of wood is expressed in pounds per cubic foot, and on the continent, in grams per cubic centimetre.

DETERMINATION OF DENSITY

The density of a piece of wood is found by dividing the weight by the volume. The weight is determined on a balance or pair of scales, to an accuracy depending on the purpose for which the determination is required. For most practical uses an accuracy of 2 per cent., *i.e.*, $\frac{1}{4}$ ounce in the pound, is adequate. There are several ways of determining the volume. The simplest is a calculation based on the direct measurement of length, width, and thickness, of a squared sample. It is recommended that the block should be not less than $3 \times 2 \times 1$ in. For smaller blocks, and those of irregular shape, the following procedure is more suitable. A beaker of water is placed on the pan or balance and counter-

balanced by sand or weights. Then the test block, suspended by a needle clamped in a stand, is lowered into the beaker and completely immersed in the water; arrangements are made so that this can be done without any of the water running over, and so that when the block is immersed it is not in contact with the sides or bottom of the beaker. Weights are then added to the opposite pan until equilibrium is restored: the weights in grams added to restore balance are equal to the volume of the test block in cubic centimetres. If the weight of the block is in ounces the volume will be required in cubic feet. This can be arrived at from the immersion method if the weights added to restore balance are English units instead of grams, and a correction factor is used. The added weight, in ounces, multiplied by 0·001 gives the volume of the sample in cubic feet. As wood is a porous substance it is necessary to coat the test block with an impervious material, such as paraffin wax, before immersion unless the wood is still "green". The block is dipped in a bath of melted wax and quickly removed, and when the coating has set the surplus wax is scraped off.

The density is found by substitution in the formulae:

$$\text{(I)} \qquad \frac{\text{Weight of block in grams}}{\text{Weight in grams added to restore balance}}$$

$$\text{(II)} \qquad \frac{\text{Weight of block in lb.}}{\text{Weight in ounces added to restore balance} \times 0{\cdot}001}$$

In (I) the density is obtained in grams per cubic centimetre and in (II) in pounds per cubic foot.

In practice it will often be simpler to use the metric system for the actual density determination, and to convert this figure to pounds per cubic foot by means of a conversion factor or graph (Fig. 61). In effect, the **specific gravity** is determined, and the density is calculated from it. The specific gravity of a substance is merely the relative density of that substance in comparison with a standard density: usually that of pure water in grams per cubic centimetre.

Water is a particularly useful standard because the weight of one cubic centimetre is one gram. In consequence, provided the weight of any given volume of water is known, the weight (or density) of the same volume of all other substances can be calculated from their specific gravities. For example, the weight of a cubic foot of water is 62·4 pounds, so that if we

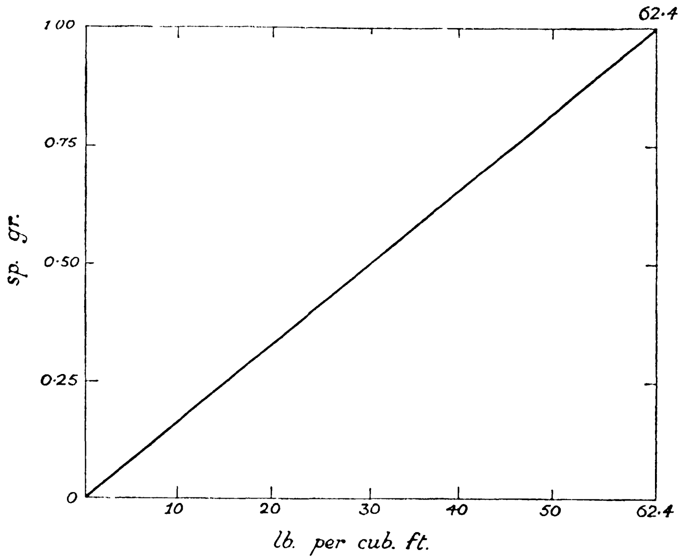


FIG. 61.—SPECIFIC GRAVITY AND POUNDS PER CUBIC FOOT.

know the specific gravity of any wood, and multiply the figure by 62·4, we obtain its density in pounds per cubic foot.

VARIATION IN DENSITY OR SPECIFIC GRAVITY OF WOOD

A piece of perfectly dry wood is composed of the solid material of the cell walls and the cell cavities which contain air and small quantities of gum and other substances. The specific gravity, or density, of the solid material of the walls has been found to be similar in all timbers, and is in the neighbourhood of 1·5; that is to say the cell walls are about one and a half times as heavy as water, and a cubic foot of

solid wood, without cell cavities and intercellular spaces, would weigh roughly 94 pounds. Different timbers, however, vary in weight from about 3, to as much as 83, pounds per cubic foot. This variation is due to differences in the ratio of cell wall to air space in different timbers, but if it were possible to compress wood into a solid mass the maximum variation would probably not exceed 4 per cent.

Besides the range of density occurring in timbers of different species there is a considerable variation between different samples of the same species. This variation occurs in different parts of individual trees, and is by no means haphazard. As a general rule the heaviest wood is found at the base of the tree, and there is a gradual decrease in density in samples from successively higher levels in the trunk. At any given height in the trunk there is usually a decrease in density from the pith to the outside of the tree in ring-porous hardwoods, but in softwoods the position is reversed, and the heaviest wood is usually found near the outside. In diffuse porous woods, however, in passing from the pith to the outside of the tree there is at first a slight increase and then a gradual decrease in density.

THE PRACTICAL SIGNIFICANCE OF DENSITY OR SPECIFIC GRAVITY

The density or specific gravity of wood is of practical interest because it is the best single criterion of strength. This is so because density and strength both depend on the thickness of the walls of individual cells, and on the proportions of different kinds of tissues. If the cell walls are thicker in one sample than they are in another the ratio of wood substance to cell cavity will be greater and, in consequence, the specific gravity will be higher. The proportions of the different kinds of tissue are important because fibres, for example, have thicker walls than parenchyma cells, and if the proportion of fibres is greater in one sample than it is in another, the specific gravity will be higher.

Two other factors, however, modify the importance of specific gravity as a criterion of strength ; namely the arrangement of the individual cells, and the chemical composition of the cell walls. If, for example, the parenchyma is distributed in broad bands these may constitute planes of weakness along which the timber will shear, despite a relatively high density for the sample as a whole. The chemical composition of the cell wall has recently been shown to be of primary importance in determining the strength of wood. For example, tests have indicated that, for timbers of equal density and moisture content, tropical species are less resistant to shock, but are stronger in compression parallel to the grain, than timbers from temperate regions. This can be accounted for by differences in the chemical composition of the cell walls.

CHAPTER VII

THE STRENGTH PROPERTIES OF WOOD

GENERAL PRINCIPLES

THE term strength applied to a material such as wood, refers to its stability to resist external forces tending to change its size and alter its shape. The effect of applying external forces to a body is to induce internal ones within the body which resist changes in size and alterations in shape. These forces are called **stresses**. The changes in size or shape are known as **deformations**, or **strains**. If the stress is small the deformation is small, and when the stress is removed there is a complete or partial recovery to the original size and shape, depending on the **elasticity** of the material. Up to a point the deformation or strain is proportional to the stress ; this point is called the **limit of proportionality**. Beyond this limit the deformation increases more rapidly than the stress, and when the stress is removed recovery is not complete. If the stresses applied exceed the forces of cohesion between the tissues a rupture or **failure** occurs.

It is important to realize that the word strength has little meaning unless it is qualified in some way ; wood has several types of strength, and a timber strong in one respect may be comparatively weak in another. Different strength properties are called into play, for example, in resisting a **compression stress** tending to crush the wood, a **tensile stress** tending to elongate it, or a **shearing stress** tending to cause one portion to slide over the remainder. In practice timber is frequently subjected to a combination of these stresses acting together, although usually one predominates. Moreover, the effect of any particular stress is complicated, because

of the elasticity of wood; a compressive stress tending to crush wood also causes it to bend. The ability to bend freely and regain normal shape is known as **flexibility,** and the ability to resist bending is called **stiffness.** Substances which are capable of suffering but little deformation without breaking are said to be **brittle,** whether the load necessary to cause deformation is large or small. For example, both cast iron and chalk are brittle substances, although the loads required to cause them to fail are very different.

It will be apparent that the strength properties of a timber are an important consideration in determining its suitability for a particular purpose. A timber for beams, posts, or struts, in buildings should possess different qualities from one required for spokes, hubs, or axles, of carts; timbers for sports goods and tool handles would not necessarily make good chopping blocks or bearings for machinery, and so on.

ASSESSMENT OF STRENGTH PROPERTIES

Much empirical knowledge exists regarding the strength properties of a few timbers. For example, the outstanding qualities of oak as a structural timber, the flexibility of ash, and the hardness of holly are well known, and similar information is available regarding some of the more common timbers in other countries. An accurate comparison of timbers of different countries, however, can only be made by evaluating their strength properties under standard conditions. The evaluations are based on the measurement of stresses and strains. A stress is expressed in terms of weight and sectional area, *e.g.*, in pounds per square inch or square foot, or simply

$$\frac{\text{load}}{\text{sectional area}}$$

and a strain in linear units in relation to the length of the object undergoing strain, or

$$\frac{\text{amount of deformation in inches}}{\text{original length in inches}}$$

Before the war the collection of strength data was more or less restricted to those timbers with established reputations in their own countries, but with the arrival on the market of a host of totally unknown timbers the need for accurate figures concerning the strength properties of many other woods has become more pressing.

This has led to the establishment of timber testing laboratories at several centres for the purpose of investigating the properties of timbers that promise to have economic possibilities. These research laboratories are situated at Princes Risborough, England ; Ottawa and Vancouver, Canada ; Madison, U.S.A. ; Melbourne, Australia ; Dehra Dun, India ; and Sentul, F.M.S.

METHODS OF DETERMINING THE STRENGTH PROPERTIES OF WOOD

Two alternative methods of determining the strength properties of wood are available ; service tests and laboratory experiments. Service tests have the advantage that they are carried out under the conditions to which timber is exposed in use, and such conditions, however nearly imitated, cannot be exactly reproduced in the laboratory. On the other hand, the data take much longer to collect, it is more difficult to control external factors, and the decentralization of the experiments increases their cost. In the circumstances, laboratory tests provide a practical solution. In the laboratory two classes of tests are made : tests on small clear specimens, and tests on timber in structural sizes. The former are of value for comparative purposes, and they provide an indication of the different strength properties of individual timbers. Since the tests are designed to avoid the influence of knots and other defects the results do not indicate the actual loads that structural members can carry, and a reduction factor, or margin of safety, must be applied to obtain safe working stresses. Tests on timber of structural size more nearly reproduce service conditions, and they are of

particular value because they take into account structural defects such as knots and splits.

The procedure for tests on small, clear specimens has been standardized. Precautions are taken to eliminate certain variables ; for example, to avoid the influence of variations in moisture content, timber is tested both in the " green " and " seasoned " conditions, and the latter figures are corrected to a standard moisture content.

THE TESTS AND THEIR SIGNIFICANCE

Tensile Strength.—Fig. 62 illustrates the test sample, and Fig. 63 the apparatus used in making tests of tensile

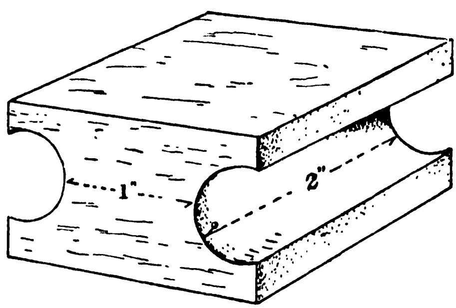


FIG. 62.—THE TEST SAMPLE for tests of tensile strength perpendicular to the grain.

strength perpendicular to the grain. The stress measured is that required to pull the specimen in two, and is calculated as follows :—maximum load in pounds to produce failure, divided by the minimum sectional area over which the force is acting, measured in square inches. Strength in tension parallel with the grain is usually not determined, because, although wood is strongest in this property, there are difficulties in the way of making the tests, and in practice timber would fail from other causes first.

A practical application of tensile stresses is in tie beams loaded from above : failure occurs through bending, which tends to elongate the fibres on the under side of the beam. High tensile strength is also of special value in timber

subjected to steam bending. The type of failure that occurs depends on the nature of the wood : thin-walled fibres break in two, thick-walled ones pull apart in the neighbourhood of the primary walls.

Compressive Strength.—Fig. 64 illustrates the apparatus used for testing compressive strength perpendicular

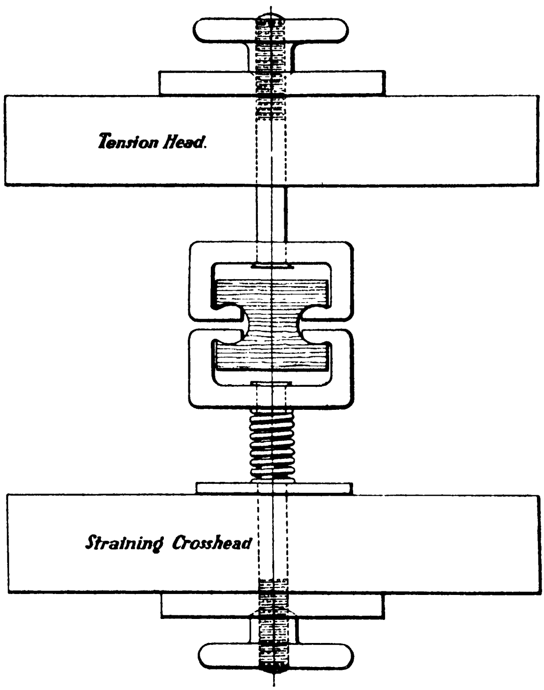


FIG. 63.—SKETCH OF APPARATUS used for determining the tensile strength perpendicular to the grain of small, clear specimens.

By courtesy of the Director, F.P.R.L., Princes Risborough.

to the grain. The stress measured is the fibre stress at the limit of proportionality, and is calculated by dividing the load in pounds, over the bearing surface in square inches.

Fig. 65 illustrates the apparatus used for making tests in compression parallel with the grain. The procedure is to apply a continuous load at a fixed speed, and to measure deformation at regular increments of load in about 20 per

cent. of the specimens, and the maximum load at the point of final failure in all samples. The calculations made, in pounds per square inch, are (a) the maximum crushing strength, (b) fibre stress at the limit of proportionality, and

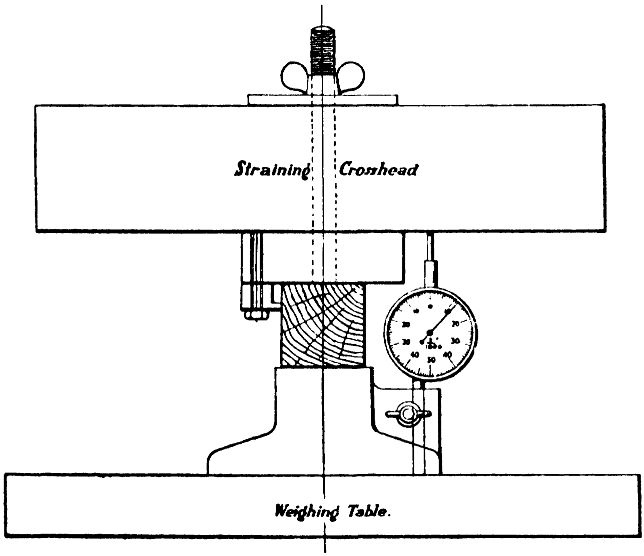


FIG. 64.—SKETCH OF APPARATUS used for determining the compressive strength perpendicular to the grain of small, clear specimens.

By courtesy of the Director, F.P.R.L., Princes Risborough.

(c) modulus of elasticity; [1] and in inch-pounds per cubic inch, (d) the elastic resilience, or work to elastic limit.[2]

High strength in compression parallel with the grain is required of timber used as columns, props, posts, and spokes. As a rule such members have a relatively great length in comparison with their sectional area, and in consequence, they are likely to fail in bending before the full crushing force

[1] $$\frac{\text{Load at limit of proportionality} \times \text{distance between the centres of the collars in inches}}{\text{Area of cross section in square inches} \times \text{total shortening at the limit of proportionality}}$$

[2] $$\frac{\text{Load at limit of proportionality} \times \text{total shortening at limit of proportionality}}{\text{Twice the volume of the test sample in cubic inches}}$$

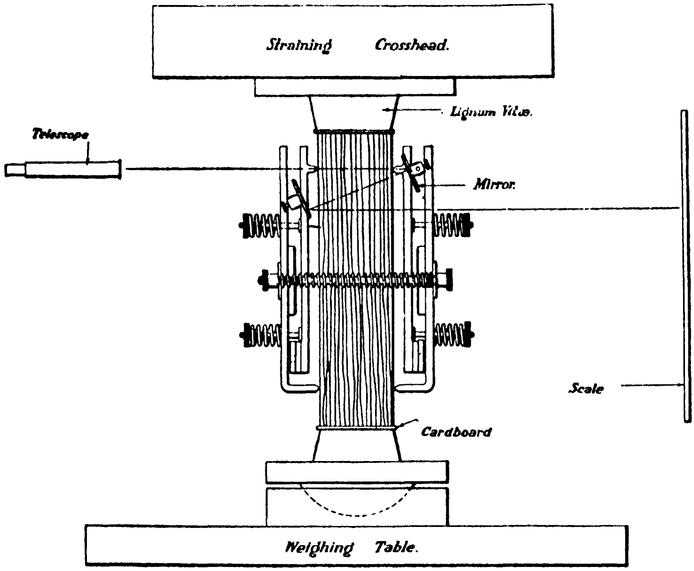


FIG. 65.—SKETCH OF APPARATUS used for determining the compression strength parallel with the grain of small, clear specimens.

By courtesy of the Director, F.P.R.L., Princes Risborough.

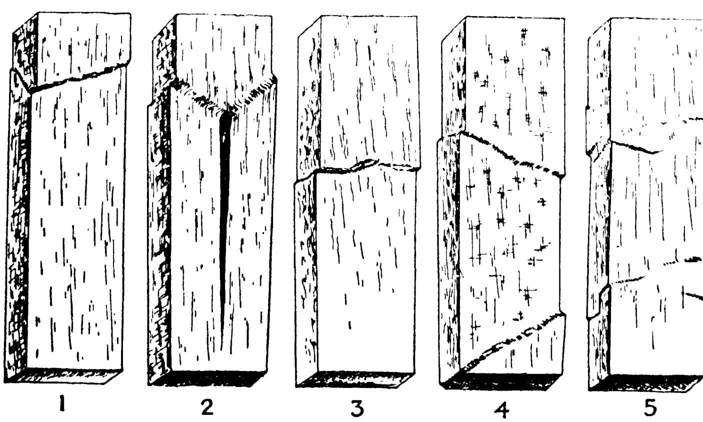


FIG. 66.—EXAMPLES OF THE TYPES OF FAILURE that occur in tests of compressive strength parallel with the grain.

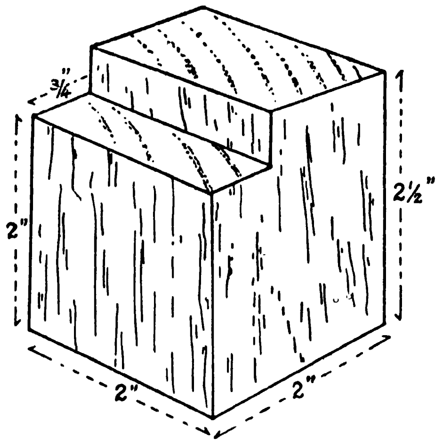


FIG. 67.—TEST SAMPLE used for tests of shearing strength parallel with the grain.

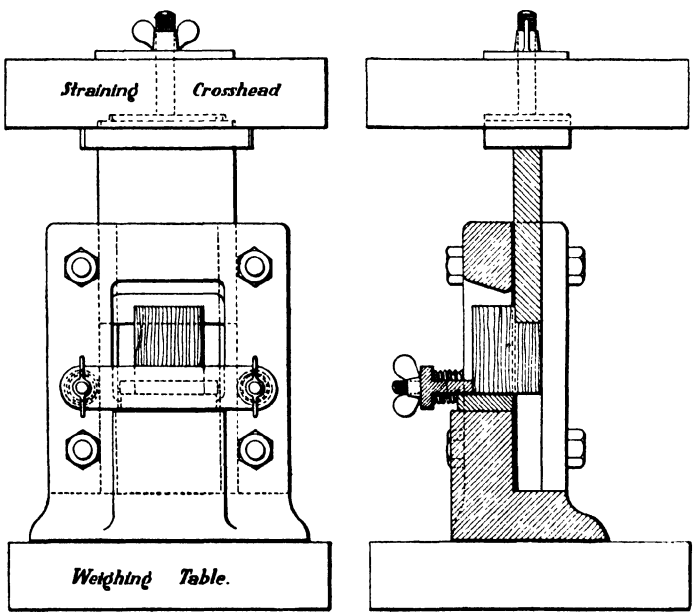


FIG. 68.—SKETCH OF APPARATUS used for determining the shearing strength parallel with the grain of small, clear specimens.

By courtesy of the Director, F.P.R.L., Princes Risborough

is applied. In order to avoid this difficulty in mechanical tests the samples are of relatively large cross-sectional area for their length. Fig. 66 illustrates the types of failure that occur in these circumstances.

Shearing Strength.—Fig. 67 illustrates the test piece, and Fig. 68 the apparatus used for determining shearing strength parallel with the grain. The stress measured is the force required to shear off the projecting lip of the test

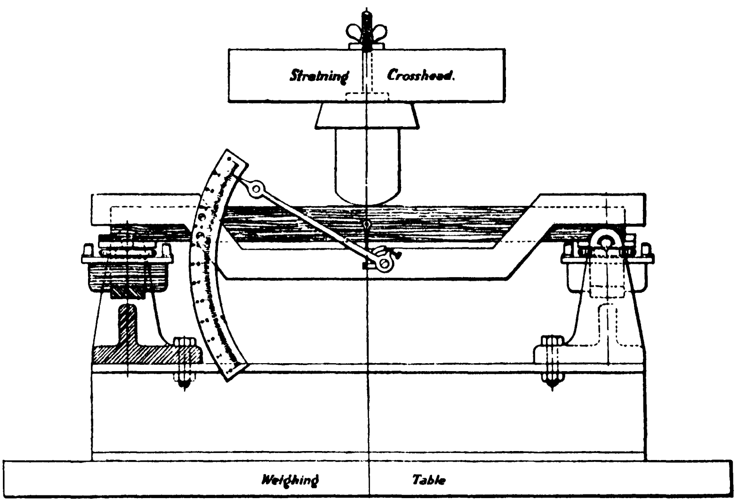


FIG. 69.—SKETCH OF APPARATUS used for static bending tests on small, clear specimens.

By courtesy of the Director, F.P.R.L., Princes Risborough.

sample, and this is obtained by dividing the maximum load in pounds, by the area of the shearing surface in square inches. Strength in shear perpendicular to the grain is not measured because timber would fail from other causes before the maximum load could be applied.

Static Bending (*cross breaking strength* or *strength as a beam*).—The three strength properties so far discussed have been considered separately, but static bending tests measure the effect of these stresses operating together. Fig. 69 illustrates the apparatus used in such tests. The test

piece is supported at both ends, with the ends free to move, and the heart face is always uppermost. The load is applied at the middle of the span, and at such a rate as to deflect the test piece to the extent of 0·015 in. per minute. The calculations made, *viz.* (a) fibre stress at the limit of proportionality, (b) fibre stress at maximum load, (c) modulus of elasticity, and (d) work in bending, are obtained in the following way :

(a) *Fibre Stress at the Limit of Proportionality :*

$$r = \frac{1{\cdot}5\ P_1 L}{bh^2}$$

where r = fibre stress at limit of proportionality in pounds per square inch,

P_1 = load at limit of proportionality in pounds,

L = span, *i.e.*, distance between the points of support,

b = breadth or width of the test piece,

h = thickness or depth of test piece.

(b) *Fibre Stress at Maximum Load :*

$$R = \frac{1{\cdot}5\ PL}{bh^2}$$

where R = the fibre stress at maximum load (or modulus of rupture) in pounds per square inch,

P = the load in pounds,

and L, b, and h, are as in the previous formula.

(c) *Modulus of Elasticity :*

$$E = \frac{P_1 L^3}{4\ Dbh^3}$$

where E = modulus of elasticity,

D = deflection in inches,

and P_1, L, b, and h, are as before.

(d) *Work in Bending.*—Whereas formulae (a) and (b) above give values for the loads sustained at different stages, work in bending is the energy consumed in reaching these stages, and is expressed in inch-pounds per cubic inch.

Static bending is a measure of the strength of a material

as a beam. In the resting position the upper half of a beam is in compression and the lower half in tension. Midway between the upper and lower surfaces is the neutral axis where both compressive and tensile stresses are theoretically nil. A shearing stress operates along the neutral axis. The result of applying a load in the middle of the span is to deflect the beam out of the horizontal. This causes a shortening of the fibres on the upper, concave surface, and an elongation of those on the lower, convex surface. As the load increases and failures develop the neutral axis moves towards the lower surface. The sequence of failures depends on the kind of wood and its physical condition. For example, in unseasoned wood the initial failure is a compression failure immediately below the point of loading, followed by either a tensile failure on the lower surface, or horizontal shear along the neutral axis. Examples of the types of fracture that occur in static bending are illustrated in Fig. 70. The clean break seen in Fig. 70, 1, usually described as "short in the grain", is characteristic of brittle timbers, and the very stringy rupture (Fig. 70, 2) is typical of the more flexible timbers.

It will be noticed that the length of span and width and depth of the timber are used in computing stress values, and that these factors influence the maximum load that can be sustained. For example, the effect of doubling the span is to halve the load that a beam of the same sectional area can carry. The effect of doubling the width, other factors remaining constant, is to double the load that can be sustained, but to double the depth is to increase the maximum supportable load fourfold. Because of this beams are made rectangular, with the greater dimension in depth. There is, however, a practical limit to the magnitude of the ratio of depth to breadth in beams; a ratio greater than 4 to 1 introduces a tendency for the member to twist when loaded.

Impact Bending.—Fig. 71 illustrates the apparatus used in impact bending tests. The test consists in dropping a hammer from successively increasing heights on to the centre

of the test piece, the test being continued to the point of complete failure or a deflection of 6 in. The data collected from impact bending tests are :—fibre stress at the limit of proportionality, (2) modulus of elasticity, (3) work in bending, and (4) height of drop to cause failure or a deflection of 6 in.

Impact bending tests provide a measure of the shock-

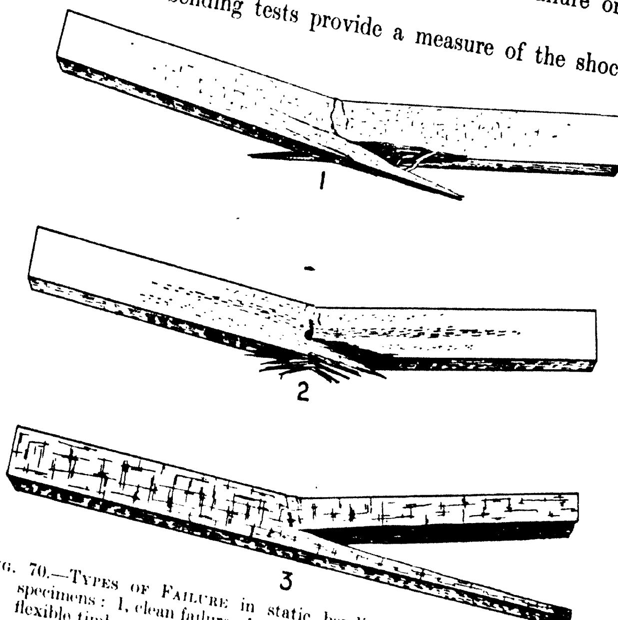


FIG. 70.—TYPES OF FAILURE in static bending tests on small, clear specimens: 1, clean failure of a brittle timber; 2, fibrous failure of a flexible timber; and 3, shearing failure.

resisting properties of wood, which are considerably in excess of the maxima for sustained loads. Shock resistance is an essential quality of timber for hammer handles and similar purposes. Timbers of this class are popularly said to be "**tough**", but this term is also applied to timbers of other types which may not be especially resistant to sudden shocks. For example, timbers which are difficult to split, and those which do not rupture until considerably deformed, are often said to be "tough". In the former cleavability is involved

and in the latter flexibility, and neither class need be especially resistant in impact bending. Further, timbers which fail with a stringy, fibrous fracture, instead of a clean break, and those which fail gradually, rather than suddenly, are also said to be "tough", although they may not be particularly resistant to sudden, excessive loads.

The combination of resistance to impact bending and the

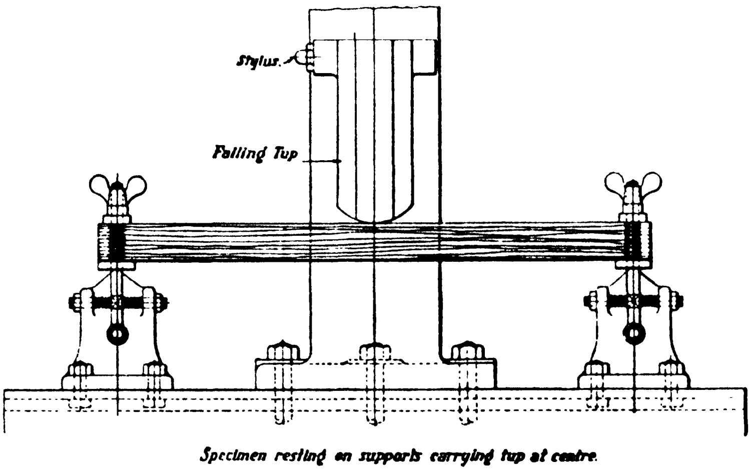


FIG. 71.—SKETCH OF APPARATUS used in impact bending tests on small, clear specimens.

By courtesy of the Director, F.P.R.L., Princes Risborough.

character of failing gradually is sometimes of special value. In places where it is impossible to forecast the exact load a wooden member may have to carry, as in mine timbers, it is a distinct advantage to employ a timber that will fail gradually, so that warning of impending collapse is given.

Hardness.—Fig. 72 illustrates the apparatus used for making hardness tests. The test consists in measuring the force required to imbed the hemispherical end of a steel rod 0·444 in. in diameter into a test piece to a depth of 0·222 in. Penetrations are made on the radial, tangential, and end surfaces. This test measures resistance to indentation, but

the popular conception of "hardness" embraces ease of cutting. This latter property is dependent on the nature of the grain, and the presence of silica and other substances in the cell cavities, quite as much as on the resistance to indentation. Several instances exist, particularly among tropical timbers, of woods which are relatively soft, measured by resistance to indentation, but which are extremely hard

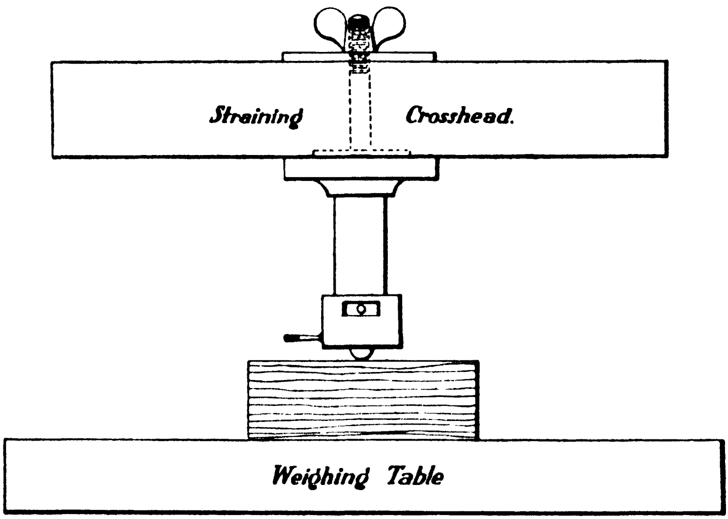


FIG. 72.—SKETCH OF APPARATUS used for testing hardness of timber.

By courtesy of the Director, F.P.R.L., Princes Risborough.

on cutting tools, *e.g.*, some of the white merantis and white serayas, and Queensland walnut.

Hardness is of value in timber for paving blocks, flooring, bearings, and other similar purposes, although for paving blocks and flooring, uniform wearing qualities are of greater importance than absolute hardness, and these may be influenced by the method of sawing: quarter-sawn material wears more uniformly than flat-sawn.

Cleavability.—Fig. 73 illustrates the test piece, and Fig. 74 the apparatus used in cleavability tests. Half the pieces are cut radially and half tangentially, and the cleavability in the two directions is calculated separately. The

stress measured is the load in pounds necessary to split the specimen in two, divided by the width of the section at the point of application of the load. The results obtained may be considerably influenced by irregularities in the grain of particular samples. Interlocked fibres, for example, provide a resistance to splitting which is due not to the actual properties of the wood, but to the arrangement in the longitudinal plane of the elements in that sample. In consequence, data from cleavability tests should be regarded solely from the comparative standpoint and not from that of absolute values. The factor which determines resistance to

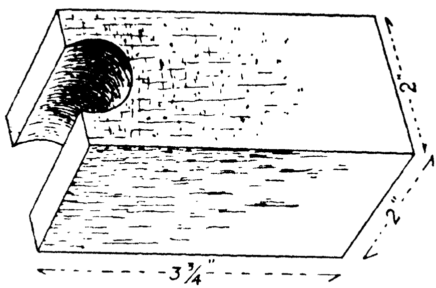


FIG. 73.—TEST SAMPLE used in cleavability tests on small, clear samples.

splitting is the arrangement of the different tissues in relation to one another. Broad rays provide planes of weakness in the radial direction, and tangential series of resin canals (as in timbers of the *Dipterocarpaceae*) planes of weakness in the tangential direction.

Cleavability denotes the readiness of a timber to split. In firewood, and material for the manufacture of tight barrels or charcoal, high cleavability is a very desirable asset ; for nail- or screw-holding purposes, as in packing-case manufacture, high resistance to cleavage is an essential quality.

Conclusions.—The limitations of tests on small, clear samples have already been indicated, but the tests are not without practical application. For example, in the absence of service tests, they are the only sound basis for comparing

the relative strength properties of different timbers, and, because external factors are more easily controlled, they are in some respects superior to service tests.

Differences in the mechanical properties of different

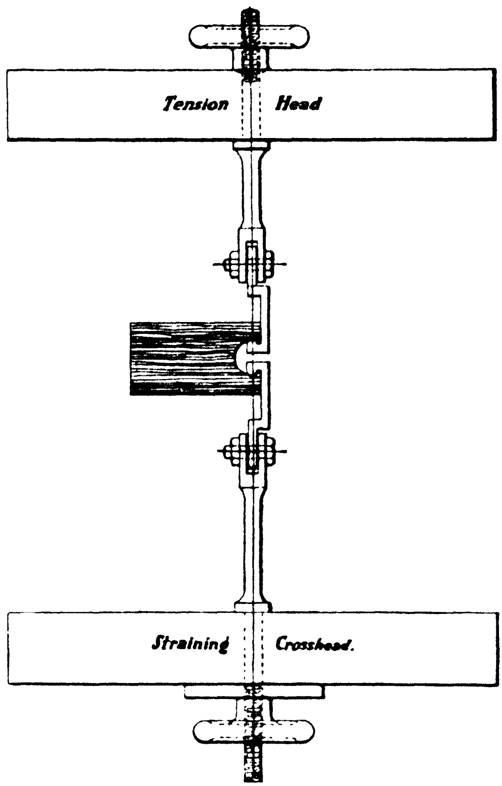


FIG. 74.—SKETCH OF APPARATUS used in cleavability test on small, clear samples.

By courtesy of the Director, F.P.R.L., Princes Risborough

timbers are obviously dependent on inherent characters, *e.g.*, the relative abundance of the different kinds of tissue and the arrangement of the individual elements in relation to one another. Various other factors, however, influence the properties of individual samples, *e.g.*, irregularities of grain ; splits and checks due to seasoning ; the presence of rot ; and

abnormalities in anatomical structure. Differences in the chemical composition of woody tissue are also important, but the presence of extractives and sapwood are negligible and can be safely disregarded.

Allowable working stresses based on tests on small, clear specimens have been determined in some laboratories, which attempt to take into account the factors mentioned in the previous paragraph. The suggested reduction factors are:[1]

(a) *In Bending :*

1/6 in dry places under cover,
1/7 outside, but not in contact with the soil, and
1/8 in wet places,

of the figures for the fibre stress at the maximum load for green timber.

(b) *In compression Parallel to the Grain :*

1/4 in dry places under cover,
1/4·5 outside not in contact with the soil, and
1/5·5 in wet places,

of the figure for the maximum crushing strength for green timber.

(c) *In Shear :*

1/10 of the average of the figures for the radial and tangential shear stresses.

(d) *In Side Compression :*

1/2·25 of the figure for the compressive strength perpendicular to the grain at the limit of proportionality.

An important factor affecting the strength properties of wood of any one species is the moisture content of individual samples. In general, below the fibre saturation point the mechanical properties of timber increase with decreasing moisture content, although the rate of increase is not identical for the different strength properties. Toughness is an exception to the general rule, since both in work to maximum

[1] Garratt, G. A., *The Mechanical Properties of Wood*, p. 133.

load in static bending, and height of drop of hammer necessary to produce complete failure in impact bending, there is usually an actual decrease as moisture content decreases; certain softwoods, *e.g.*, sitka spruce, show an increase in toughness

TABLE I

AVERAGE INCREASE (OR DECREASE) IN VALUE OF VARIOUS STRENGTH PROPERTIES EFFECTED BY DECREASING (OR INCREASING) MOISTURE CONTENT 1 PER CENT. WHEN AT ABOUT 12 PER CENT.[1]

Property	Per cent.
Static bending :	
Fibre stress at elastic limit	6
Modulus of rupture	4
Modulus of elasticity	2
Work to elastic limit	8
Work to maximum load	-1
Impact bending :	
Fibre stress at elastic limit	4
Work to elastic limit	5
Height to drop of hammer causing complete failure	-3
Compression parallel to grain :	
Fibre stress at elastic limit	5
Crushing strength	4
Compression perpendicular to grain :	
Fibre stress at elastic limit	6
Hardness—end	3
Hardness—side	1
Shearing strength parallel to grain	4
Tension perpendicular to grain	1

with decrease in moisture content. In other words, dry wood will support a far greater load than green timber, provided it has not been weakened by the development of seasoning defects, but it will not bend so far before failure occurs; it is more brittle. For most purposes the margin of safety in general use is such that the increase in brittleness is not of consequence. Mine timbers, however, are an exception,

[1] Garratt, G. A., *The Mechanical Properties of Wood*, p. 133.

since it is not always possible to determine what loads such timbers will have to carry, and brittleness may become a serious fault. It has been found that small clear specimens of thoroughly air-dry wood (12 per cent. moisture content) have practically twice the strength in bending and endwise compression of the same material when unseasoned. When kiln-dried to approximately 5 per cent. moisture content the increase in strength may be threefold. Table I shows the average increase or decrease in value of various strength properties, effected by decreasing moisture content by 1 per cent., for timber previously dried to about 12 per cent.

It must not be overlooked that the development of seasoning defects may offset any increase in strength properties as timber dries. Moreover, the figures given in Table I are *average* figures for several species, and considerable variation is shown not only between different species, but also between different samples of the same species. A further point of interest is that timber once dried below a given moisture content has slightly lower strength properties, and is more brittle, than material that has never been dried below this state.

CHAPTER VIII

THE MOISTURE IN WOOD

THE OCCURRENCE OF WATER IN TIMBER

THE timber of living trees and freshly felled logs contains a large amount of water, which often constitutes a greater proportion by weight than the solid material itself. The water has a profound influence on the properties of wood, affecting its weight, strength, shrinkage, and liability to attack by some insects and by fungi which cause stain or even decay.

It has been mentioned that the cells of wood are hollow, and that in the living tree many of the cell cavities are filled with water. Moreover, the solid material of which the cell walls are composed is itself saturated with water, much in the same way as seaweed that has just been uncovered by the tide. As might be expected, the " free " water in the cell cavities has very little influence on the properties of wood other than its weight ; it may be compared with water in a bottle. If the " free " water were removed from the cavities of the wood the properties of the timber would not be greatly changed any more than are those of a bottle emptied of its contents. It is actually impossible to remove all the water in the cell cavities without removing some from the cell walls, but as a starting point of our discussion it is convenient to imagine the theoretical state when the cavities are empty and the cell walls are saturated ; this state is known as the **fibre saturation point.**

Reverting to the analogy between seaweed and wood, it may be recalled that the former is sometimes used as a

weather guide because it is **hygroscopic** ; that is, it is able to absorb moisture from a humid or damp atmosphere, and allows water to evaporate when the atmosphere is dry. Wood behaves in a similar way, in that there is a constant interchange of water between wood and air depending on which is the wetter. When " green " wood is exposed to dry air it loses water, first the free water in the cell cavities, and when this is removed, further loss is from the cell walls. With the loss of water from the cell walls wood shrinks, and, like seaweed, becomes stiffer and harder. If dry wood is placed in a humid atmosphere it absorbs water, and swells, and as it does so it becomes less rigid.

The amount of free water that a piece of wood can retain is governed by the volume of the cell cavities and intercellular spaces. The volume of these, as we have seen when discussing density, depends on the amount of wall substance in any given volume of wood, and the greater the proportion of wall substance the smaller the proportion of free water, and *vice versa.* This relation is illustrated theoretically by the curve in Fig. 75. The graph is only approximate, because infiltrates of different specific gravity from wood substance influence the position. The presence of infiltrates of higher specific gravity than wood substance cause the percentage of water read from the graph to be too low, and the presence of those of lower specific gravity cause the percentage to be too high.

We have seen that cell walls consist of several concentric layers, and that the layers are composed of fibrils which we pictured as minute, needle-like units. The water in the cell walls appears to be in films between these units, more or less like mortar in a brick wall. There is a limit to the thickness of the films, and consequently to the amount of water in the cell walls. In most timbers the walls can hold about 25 to 30 per cent. of their dry weight ; when this amount is present the wood is at fibre saturation point.

"MOVEMENT" IN WOOD

The tendency of wood to shrink or swell with changes in the moisture content of the atmosphere is a factor inseparable from the material. This characteristic behaviour of timber is popularly called "working" or "movement"; it cannot be eliminated by any particular method

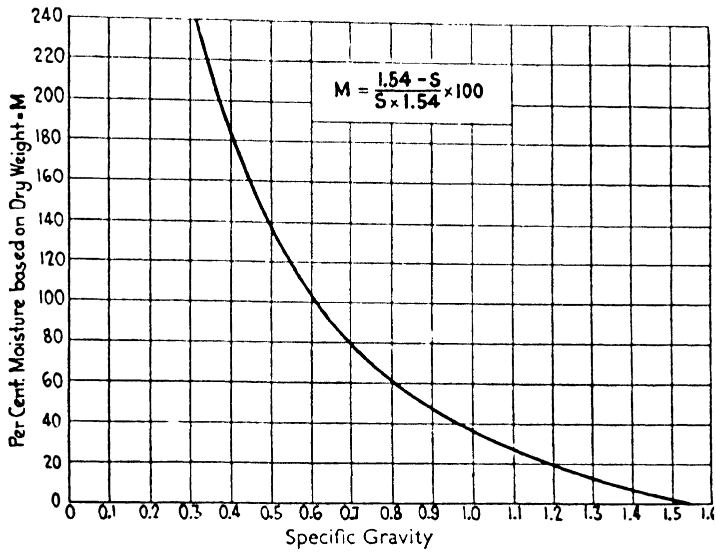


FIG. 75.—Relation between specific gravity and theoretical maximum moisture content. For explanation see text.

By courtesy of A. Koehler, Esq.

of seasoning, storage, or treatment, although the deleterious results can be minimized by taking certain precautions.

It is a matter of general observation that timber shrinks hardly at all along the grain; in drying from the green to the oven-dry condition the shrinkage in this direction amounts to only a few tenths of 1 per cent. In the radial and tangential directions, however, movement is appreciable, and in drying from the green to the oven-dry condition shrinkage in the radial direction may amount to 7 per cent., and in the tangential to as much as 14 per cent., and average

figures for many timbers are 4 and 8 per cent. respectively. The movement occurring under ordinary atmospheric conditions is, of course, much less than occurs over the wide range from green to the oven-dry state.

It will be seen that radial shrinkage is only about half as much as the tangential; this is due to the restraining influence of the rays. The difference in shrinkage in the two directions plays an important part in the utilization of wood, and much of the distortion which occurs as wood dries may be accounted for in this way. Quarter-sawn material naturally shrinks less than flat-sawn, and advantage is often taken of this in certain uses of woods, *e.g.*, flooring. The ratio of tangential to radial shrinkage varies in different timbers from as low as 1 : 1 to as high as 7·9 : 1. Honduras mahogany is exceptional in having an extremely low ratio, that is to say, tangential shrinkage is very little greater than the radial; this fact, coupled with the low shrinkage of the wood, renders it particularly suitable for many special purposes, *e.g.*, cabinet work, backing for engraving plates.

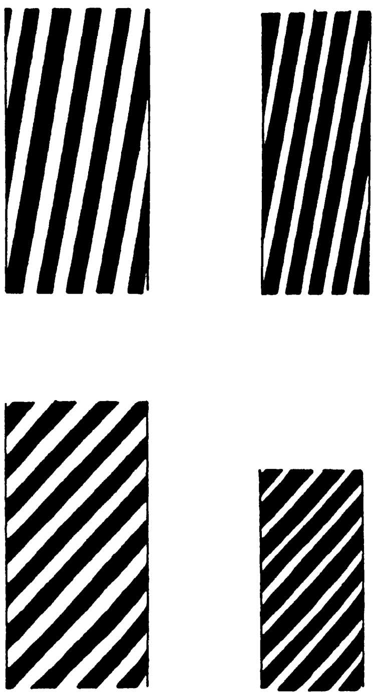


FIG. 76.—FIBRIL STRUCTURE and its relation to shrinkage.

The fibrillar structure of cell walls, and the occurrence of water as films surrounding the fibrils, helps to explain the shrinkage and swelling of wood with changes in moisture content below the fibre saturation point. As water is removed, the films become thinner and the fibrils pack

closer together, causing shrinkage ; when dry wood absorbs water the films become thicker and force the fibrils further apart, causing the wood to swell. The comparatively low shrinkage in the longitudinal direction may be explained by the fact that the fibrils are arranged in a steep spiral, as may be seen from Fig. 76 ; as the fibrils pack closer together the reduction in the space they occupy is much greater in the transverse than in the vertical plane.

Variation in the amount of movement in timbers of different species is not fully understood. It may be accounted for in part by differences in anatomical structure, *e.g.*, the size and number of the rays, but there is no doubt that variations in the fibrillar structure of the cell walls play an important part.

DETERMINATION OF MOISTURE CONTENT

Oven-dry Method.—Since the properties of timber depend so much on the amount of moisture it contains it is frequently necessary to know exactly how much is present in a particular sample. The **moisture content** of timber is usually expressed as a percentage of the dry weight of the sample. The ratio is simply :

$$\frac{\text{Weight of water present}}{\text{Dry weight of wood substance}} \times 100$$

and is obtained as follows :

$$\frac{\text{Initial wt. of sample} - \text{dry wt. of sample}}{\text{Dry wt. of sample}} \times 100$$

The initial weight of a sample is the actual weight at the time of test, and the dry weight is the weight of the sample after the moisture has been expelled.

Apparatus.—The apparatus required is a simple balance, and some form of drying oven which can be maintained at a more or less constant temperature. The type of balance suitable in commercial practice is one of the self-registering

type, weighing to an accuracy of 0·5 gram and up to a maximum of about 500 grams. The metric system is recommended as it simplifies the calculations ; there is no other objection to the use of English units in moisture-content determinations. Various types of drying ovens are on the market, but all are essentially similar in principle, in spite of makers' claims to special advantages. The essential points to look for are (1) the capacity of maintaining an even temperature between 95° and 105° C. (205°-220° F.), (2) good ventilation (a sample heated in a closed box would, of course, not lose moisture once the surrounding air space had become saturated), and (3) source of heat. For heating, electricity has the advantage of simplicity, but gas, oil, or steam, may equally well be used ; it is entirely a matter of convenience. Designs of simple ovens, one electrically, and the other steam heated, are given, and their method of construction described, in a leaflet issued by the Forest Products Research Laboratory, Princes Risborough.[1]

Sampling.—Provided attention is paid to the essential points enumerated above, the method of selecting test blocks is of greater importance than any particular features of the apparatus used for weighing and drying the samples. It is essential that the sample shall be representative, not only of the board or plank from which it is cut, but also of the parcel as a whole. For example, the moisture content of the sapwood of some species varies appreciably from that of the heartwood, so that the proportion of sapwood in the test blocks should be similar to that in the whole parcel. In practice the moisture content of a large quantity of timber should not be based on a single sample, but on two or three selected at random. When taking sample boards from a stack of timber outside ones should be avoided, as these often differ appreciably in moisture content from those of the interior. Having selected the samples, off-cuts of the full cross section of each should be taken not less than 9 to 12 in.

[1] Forest Products Research Bulletin No. 14, 1932. H.M. Stationery Office, London.

(preferably 2 ft.) from either end, and $\frac{3}{8}$ to $\frac{5}{8}$ in. along the grain. Larger pieces take much longer to dry, and are not necessary. Each sample should be reasonably free from knots which, although they influence the moisture content of the board as whole but little, may introduce a serious error in the case of the small sizes recommended as test blocks.

Procedure.—Once the test block has been cut out, rapidity of weighing is essential to minimize the chance of the sample picking up, or losing, moisture. This is of particular importance when the samples are oven dry, as they will absorb moisture in a very short space of time. After the initial weighing the samples should be transferred to the drying oven. This should be run at a temperature of 60° C. for the first few hours to prevent the moisture in the centre of the samples being sealed in, as a result of case-hardening. The temperature can be raised to 105° afterwards, and the samples left in the oven over night. They should be re-weighed first thing on the following morning, and again some hours later. If there is no appreciable difference between the last two weighings, the lower may be taken as the oven-dry weight. If, however, the second weighing shows an appreciable drop, drying must be continued for a further period. Drying in an oven does not expel all the moisture, but the small discrepancy—the last one per cent. or so—is not of practical importance.

Example.—A test block with an initial weight of 88·7 grams weighed 76·7 grams twenty-four hours later, and 76·6 grams four hours later still. Accepting the second of these re-weighings as the dry weight, the moisture content of the sample was :

$$\frac{88{\cdot}7 - 76{\cdot}6}{76{\cdot}6} \times 100, \text{ or } \frac{12{\cdot}1}{76{\cdot}6} \times 100 = 15{\cdot}8 \text{ per cent.}$$

The presence of oils or resins introduces an error in the calculated moisture content because these substances, being volatile, are lost in the process of drying, and are counted as moisture, so that the calculated figures are too high. This

should be borne in mind when dealing with such timbers as gurjun, apitong, keruing, and resinous samples of pitch pine.

Single calculations of moisture content are useful for determining whether a stack of timber is suitable for a particular purpose, *e.g.*, indoor or outside use, but occasions will often arise when it is desirable to determine moisture contents of the same material from time to time over a period. This is the case, for example, when studying the progress of seasoning in a stack. Such work can be greatly simplified if the test boards are so arranged in the stack that they can be withdrawn without pulling down the stack on each occasion. Having estimated the moisture content of the test boards from samples cut in the normal way at the time of the first test, the moisture contents can be calculated on subsequent occasions from re-weighing of the boards alone.

Example.—The initial weight of a test board is 51 lb., and its moisture content, as determined from samples, is 27·5 per cent. Let its dry weight equal "x", then $x + \frac{27{\cdot}5x}{100} = 51$, and $x = 40$. After a lapse of a week the board is re-weighed and found to scale 48·3 lb. We know the dry weight from the previous calculation, so that the moisture content of the moment can be determined by substitution in the formula

$$\frac{\text{Present weight} - \text{dry weight}}{\text{Dry weight}} \times 100$$

in this case—

$$\frac{48{\cdot}3 - 40{\cdot}0}{40} \times 100 = 20{\cdot}8 \text{ per cent.}$$

The process can be repeated as often as is required, by simply re-weighing the test boards and calculating the moisture content as in the example above.

Moisture Meters.—The moisture content of wood may be determined indirectly by measuring some other property which varies proportionately with changes in moisture content. For example, the electrical resistance of wood is an

index of its moisture content, because the electrical conductivity increases proportionately with increase in moisture content over a certain range. Fortunately the range over which this relation is most marked is that from the oven-dry state to the fibre saturation point, and this fact makes **electrical moisture meters** practicable.

Moisture meters are in use on a commercial scale in America, the usual type consisting of a handle, or hammer, fitted with spikes and wired to an electrical recording instrument. The spikes are driven into the face of a board, so that the points penetrate to a certain fixed depth. When the current is switched on a pointer records the amount passing through the board, but the dial is graduated to read the moisture content direct. Correction factors, or different scales, are required for different species, as the electrical conductivity of wood at any given moisture content is not the same for all species.

Besides the question of cost, and the fact that a different scale, or correction factor, has to be used for each species, moisture meters have other limitations. In the first place the figure read off the scale is the moisture content of the piece to the depth of penetration of the spikes on the hammer : the surface moisture content of a thick plank, particularly in the early stages of seasoning, is likely to be very different from that of the interior, and the meter will record too low a figure for the plank as a whole. On the other hand, a surface film of water left by a shower of rain will cause the reading to be too high. In the second place, the instruments are delicate, and require careful handling and considerable technical knowledge, to maintain them in an efficient condition. Moisture meters, however, have distinct possibilities in that they give results almost instantaneously, and, if for no other purpose, they are invaluable in the selection of material from a stack when a narrow range in moisture content between individual pieces is essential.

Estimation of Moisture Content from Measurement of Shrinkage.—The foregoing methods do not

demand especially elaborate apparatus, or appreciable technical skill, but they are suitable only where moisture-content determinations are a routine practice, as they should be in timber yards, joinery works, and other wood-using factories generally. A simple test is available for checking the moisture content of timber without the use of special apparatus; it is based on measurement of shrinkage, and is useful in determining the suitability, as far as adequate seasoning is concerned, of timber on a job.

The procedure is to select a representative scantling, and one that has not been lying on top of the pile, and to cut off a cross section, about ½ in. along the grain, some 2 ft. from one end. Measure the width and thickness of the sample accurately to the nearest sixty-fourth of an inch. To ensure re-measurement in precisely the same line, it is advisable to put small dots at the points of measurement. Expose the sample in a well-ventilated, inhabited room for a few days, *i.e.*, 4 to 7 days, and then re-measure. In this period the sample should reach equilibrium with its surroundings, and the decrease in width and thickness will represent the amount of shrinkage that will occur when the timber is put into service. If this test is carried out in summer, greater shrinkage than that actually measured may be expected to occur in winter, because domestic heating dries the air more than do summer temperatures. It is possible to obtain an idea of the amount of shrinkage to be expected without the necessity of measurement, by matching the test sample from time to time with the identical piece of timber from which it was cut. Measurement is more satisfactory, however, and more convenient when the timber to be tested is some distance from the office where the experiment is carried out.

This test gives information as to the state of the timber at the time of inspection. If there is a considerable delay between the time of test, and the time when the timber is put into use, a loss, or increase, of moisture may occur in the interval. Little change is likely to take place in a period of

3 or 4 weeks if the timber is close piled and covered with a tarpaulin, but if the timber is properly stacked and roofed over some drying (down to 15 or 16 per cent.) may occur during such a period in the summer months. Little or no drying, even under the most favourable conditions, is likely to occur out-of-doors in winter. Timber of low moisture content will absorb moisture while awaiting fixing: up to about 15 to 16 per cent. in summer, and up to 18 to 20 per cent. in winter, if protected from the weather, but if exposed to rain the figures quoted may be exceeded even in a short space of time.

VARIATION IN MOISTURE CONTENT OF GREEN TIMBER

The amount of moisture in timber of living trees and newly felled logs is primarily a question of species; in some it is only about 40 per cent., and in others it may exceed 200 per cent. of the dry weight. In Douglas fir, for example, the average moisture content of newly felled trees is about 40 per cent., but in the American sweet chestnut it exceeds 120 per cent. In most species there is usually a marked difference in the moisture content of sapwood and heartwood; particularly is this the case with softwoods. In pitch pine, for example, the moisture content of the sapwood exceeds 100 per cent., and the heartwood ranges from 30 to 40 per cent. Moisture content may also vary with height in the tree: butt logs of redwood and western red cedar often sink in water, although the upper logs float. In species with a marked difference between the moisture content of sapwood and heartwood the position may, however, be reversed, owing to the upper logs containing a higher percentage of sapwood of high moisture content.

There is no evidence in support of the widely held opinion that timber felled in winter, when the sap is said to be "down", is drier than that felled in summer, when the sap is said to be "up". In fact the evidence points the other

way (*vide* Fig. 77). In Germany figures have been collected for birch, poplar, and pine, showing that the moisture content of these timbers was lower between June and September than between November and March, the minimum occurring in June or July and the maximum in December, January, or February. Similar figures have been collected for several species in America, and in no case was the moisture content in winter found to be lower than that in summer. In the light of these figures the prejudice against summer felling

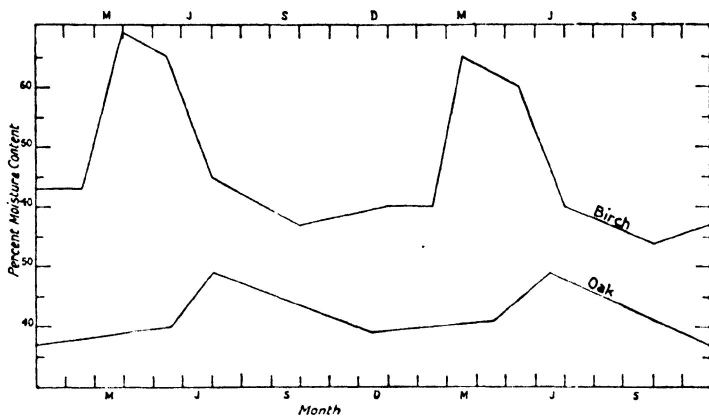


Fig. 77.—Variation in Moisture Content of trees at different seasons: M = March, J = June, S = September, D = December.

From "The Structure and Life of Forest Trees", by courtesy of Messrs. Chapman & Hall.

cannot be sustained on the grounds usually advanced. There is some justification on scientific grounds, however, for preferring winter felling. Chief of these is the reduced activity of insects and fungi during the cool months, and the lower degrade in seasoning resulting from a slowing down of the drying process. The prejudice no doubt arose, partly as a result of practical experience which showed that winter felling gave better results, and partly owing to economic necessity, as agricultural activities absorbed the population in the summer months and left them free for work in the woods during winter.

VARIATION IN MOISTURE CONTENT OF SEASONED TIMBER

Considerable variation in moisture content occurs in different pieces of so-called "air-dry" or "seasoned" timber. The moisture content at any given moment will depend on the atmospheric conditions to which the timber is exposed, the stage reached in the drying process, the dimensions of the piece, and the species.

However prolonged the period, or favourable the conditions, drying does not continue indefinitely: a stage is reached when there is no further interchange of moisture between the wood and air. Any subsequent change in temperature, or increase or decrease in moisture in the air, however, upsets this balance, and there is a further exchange of moisture until a new state of equilibrium is reached. This is due to the fact that, when equilibrium conditions are established, the amount of water available is distributed between air and wood in certain definite proportions.

Much of the so-called "seasoned" timber on the market today is little more than surface dry, and must be expected to shrink appreciably until it eventually comes into equilibrium with ordinary, atmospheric conditions. Timber in old houses and furniture, on the other hand, has already reached the equilibrium state and is, therefore, relatively stable. If, however, the atmospheric conditions are changed, as for example, by the installation of central heating in a previously coal-heated house, the moisture equilibrium will be disturbed and noticeable movement will occur in the timber. A case is known of genuine Stuart pine panelling that had been in position for 300 years shrinking when re-erected in a centrally-heated room.

In scientific language, the moisture content of air-seasoned timber, at any given temperature and in equilibrium with its surroundings, bears a direct relation to the **relative humidity** [1]

[1] Atmospheric air normally contains some water vapour; and for every temperature there is a definite maximum amount that air can hold. When

per cent. For exterior sheeting, framing, siding, and exterior trim, the corresponding figures are 9 to 12 per cent. in the first two regions and 7 to 12 per cent. in the third.

TABLE II

MOISTURE CONTENT SPECIFICATIONS FOR CONSTRUCTIONAL TIMBERS IN GREAT BRITAIN [1]

Timber for	Moisture Content not to exceed
	Per cent.
General carpenter's work	25
High-class carpenter's work . . .	20
General joinery work	15
Best joinery, block and strip flooring, panelling, and decorative work	9-12* 10-14†

* For centrally-heated rooms and buildings.
† For rooms and buildings not centrally-heated.

In the United Kingdom and most regions of the United States, thoroughly air-dry timber, seasoned under the most favourable conditions, contains 12 to 15 per cent. of moisture ;

TABLE III

MOISTURE CONTENT SPECIFICATIONS FOR FURNITURE TIMBERS IN GREAT BRITAIN [2]

Timber	Environment			Average Conditions
	Bedroom	Living room	Office	
	Per cent.	Per cent.	Per cent.	Per cent.
Oak (American white) .	13·6	12·8	12·5	13
Mahogany (Cent. American)	12·8	12·0	11·8	12·3
Scots pine	12·2	11·3	11·2	11·5

in the more humid tropics, *e.g.*, Malaya, 14 to 18 per cent. ; and in hot arid regions 8 to 12 per cent. or even less.

The rapidity with which adjustments to changes in the

[1] Figures from Report of the F.P.R. Board for the year 1930, by courtesy of the Director, F.P.R.L., Princes Risborough.

[2] Figures from "The Moisture Content of Wood with special reference to Furniture Manufacture", Bull. No. 5, 1929, by courtesy of the Director, F.P.R.L., Princes Risborough.

relative humidity of the atmosphere occur depends on the dimensions of the timber and on the difference between the initial, and equilibrium, moisture contents of wood. The adjustment is more rapid when the difference is large, and becomes extremely slow as equilibrium conditions are approached. But for this, movement in timber would be greater and more frequent than it is. By installing timber of a moisture content midway between the range to be expected in service, movement is reduced to a minimum.

The equilibrium moisture contents cited in the tables are maximum or average figures for timber in inhabited buildings, and a deviation of $\pm$ 2 per cent. from these figures is permissible. Special precautions, however, are necessary when installing woodwork in new buildings ; it is not sufficient merely to select timber of the correct moisture content for subsequent conditions. When the shell of a building is completed the equilibrium moisture content within may be expected to be between 16 to 20 per cent., according to the season. If joinery and finishings of 10 to 12 per cent. moisture content are installed in these circumstances some swelling and even buckling is to be expected. On the other hand, it would not do to use timber of 16 to 20 per cent. moisture content, because appreciable shrinkage would occur later. Two alternative courses are to be recommended : either temporary heating should be installed and the building dried out before the joinery and finishings are fixed, or fixing should be delayed until the building has had a reasonable opportunity of drying out on its own account ; for this to occur a period of 3 to 6 months is necessary.

The practice of baking buildings in the early days of occupation is thoroughly unsound, and may result in considerable damage to the timber, because even the most carefully seasoned and fitted joinery will shrink and distort if suddenly exposed to much drier conditions than those for which it was prepared. The proper course is to employ no more heat than is necessary for occupational use, and this applies both before and after the joinery is fixed. Pre-baking

is likely to give trouble with the carcassing timber and lath-plaster work.

Size, density, species, and initial moisture content of the timber, and rate of air circulation and its temperature, are, then, the factors which influence the rate of adjustment of the moisture in wood to the relative humidity of air. It may also be mentioned that flat-sawn material will lose moisture more rapidly than quarter-sawn, and sapwood more rapidly than heartwood.

FACTORS AFFECTING THE HYGROSCOPICITY OF WOOD

We have seen that the hygroscopic nature of wood is responsible for causing variations in the moisture content of

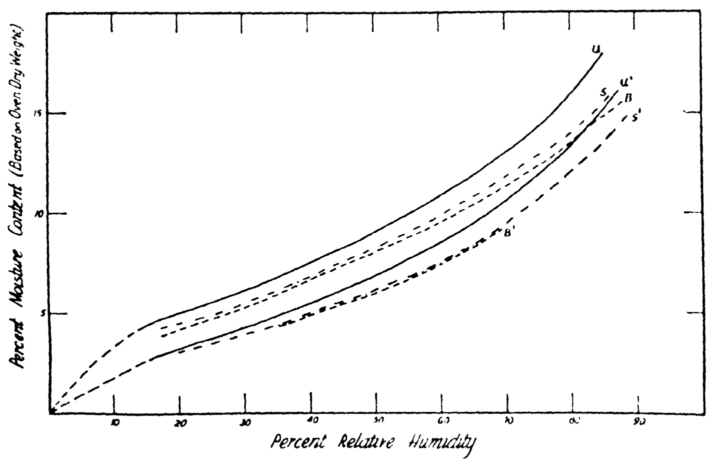


FIG. 80.—CURVES showing effect of boiling and steaming on the hygroscopicity of wood. U = untreated, U^1 = the same, but absorbing moisture from the dry conditions; S = steamed, S^1 = steamed wood absorbing moisture from the dry state; B = boiled, B^1 = boiled wood absorbing moisture from the dry state.

By courtesy of the Director, F.P.R.L., Princes Risborough.

timber to follow changes in the relative humidity of the atmosphere. Further, it has been mentioned that hygroscopicity cannot be eliminated : it can, however, be permanently

reduced by certain treatments. A permanent reduction in the hygroscopic properties of wood is effected by high-

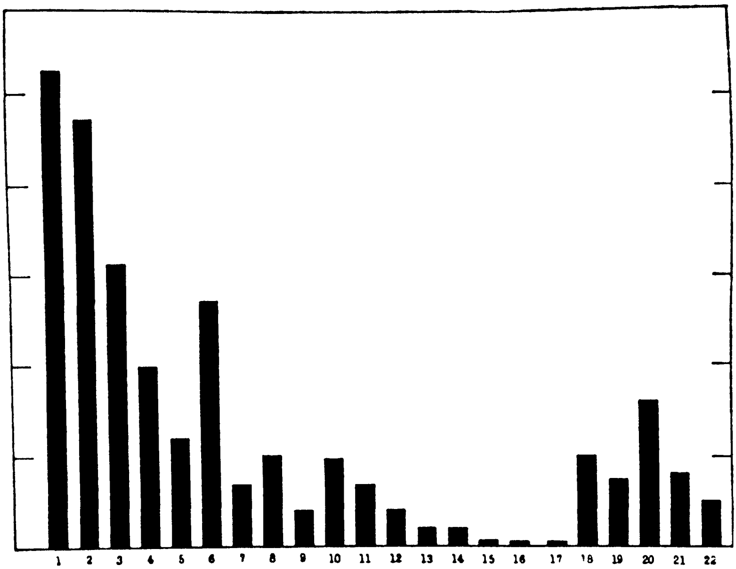


FIG. 81.—RELATIVE EFFECTIVENESS of protective coatings against moisture absorption by dry wood exposed to a saturated atmosphere for 17 days.

1. Untreated wood.
2. 5 coats linseed oil, 2 coats wax.
3. Impregnation with paraffin and gasoline (vacuum and pressure).
4. Cellulose varnish (vacuum and pressure).
5. 3 coats of cellulose varnish.
6. Filler and 3 coats spar varnish. (Poorest of 43 tested.)
7. Filler and 3 coats of spar varnish. (Best of 43 tested.)
8. Filler and 2 coats of enamel (red-lead pigment) plus varnish.
9. Filler and 2 coats of enamel (white-lead pigment) plus varnish.
10. Filler and 3 coats commercial enamel (average of 11 brands).
11. Filler and 3 coats commercial enamel (best brand).
12. Filler and 3 coats of shellac and aluminium powder.
13. 5 coats of bakelite plus 5 coats of varnish.
14. Metal leaf coatings: filler and shellac or varnish undercoat and varnish size and aluminium leaf and 2 coats of varnish shellac or enamel (average of all types).
15. Ditto (best type).
16. Sprayed with copper or aluminium and 3 coats of varnish.
17. Electroplated with copper.
18. Filler and 3 coats, brushed. (Average of 7 varnishes.)
19. Filler and 3 coats, dipped. (Average of the same 7 varnishes.)
20. Filler and 2 brush coats.
21. Filler and 6 brush coats.
22. Filler and 12 brush coats.

From A. Koehler, "The Structure, Properties and Uses of Wood" by courtesy of the author.

temperature treatments, steaming, boiling, and certain chemical means. The higher the temperature, and the longer it is maintained, the more is hygroscopicity reduced, but too severe treatments may damage the timber. Boiling and steaming act similarly, as may be seen from the curves in Fig. 80. The solid lines are drying curves for untreated wood, and the dotted ones are those for timber that has been either steamed or boiled. Boiling will be seen to be more effective than steaming. Creosote and hot paraffin have been found to reduce hygroscopicity, but some chemical treatments actually increase it, *e.g.*, caustic soda. Others again, *e.g.*, solutions of common salt, and sugar (Powell process), do not influence hygroscopicity so much as they reduce subsequent movement in timber. It has also been claimed that ozone and ammonia reduce shrinkage, although the effectiveness of the former has recently been questioned.

It is not known how the hygroscopic properties are altered by the different treatments, and in practice it does not matter whether there is an actual reduction so long as subsequent movement is reduced. Paints, varnishes, and linseed oil, for example, are effective because they reduce the rate at which moisture can be absorbed by timber: they offer mechanical resistance to the exchange of moisture between the air and wood, as a result of their semi-permeable nature. Of several different protective coatings tried, aluminium leaf, between a filler and shellac under-coat and two coats of varnish or enamel, was the most efficient. Varnishes, enamels, and paints containing aluminium powder, were less effective, but considerably more efficient than ordinary paints; and linseed oil, and wax had little effect at all. Fig. 81 illustrates the relative effectiveness of several different protective coatings. It will be seen that the selection of a suitable paint or varnish is an important matter, and can be very effective in reducing movement in timber. Moreover, protective coatings in no way change the strength properties of wood.

CHAPTER IX

THE CONDUCTIVITY AND HEAT VALUE OF WOOD

HEAT CONDUCTIVITY

In many situations the ability of a substance to resist the passage of heat, electricity, or sound, is of the greatest importance. Dry wood is one of the poorest conductors of heat, and this characteristic renders it eminently suitable for many of the uses to which it is put every day, *e.g.*, as a building material, in the construction of refrigerators or fireless cookers, and as handles of cooking utensils. The handle of an all-metal teapot becomes as hot as the teapot itself in a relatively short space of time, but a wooden one remains comparatively cool, and feels the more so because the heat absorbed by wood is given up more slowly than that absorbed by a good conductor.

The transmission or conduction of heat depends on two factors: (a) the **specific conductivity** and (b) the **specific heat** of the intervening material. Although the specific conductivity of dry wood substance is low, that of timber is even lower, for, as we have seen, wood is a cellular substance, and in the dry state the cell cavities are filled with air which is one of the poorest conductors known. The cellular structure of wood also partly accounts for the fact that heat is conducted about two to three times as rapidly along, compared with across, the grain, and that heavy woods conduct heat more rapidly than light, porous ones. This may be explained in the main from the fact that the wood substance of which the walls are composed is a better conductor than the air filling the cell cavities.

The specific heat of a substance is a measure of the amount of heat required to raise its temperature by a stated amount. The specific heat of wood is about 50 per cent. higher than the specific heat of air, and four times as high as that of copper. It has already been inferred that the conduction of heat through wood is a matter of importance in the kiln drying of timber, since one of the aims of this process is to raise the temperature of the interior of planks and boards in the kiln. In these, and similar circumstances, the high specific heat of wood is a disadvantage. Fortunately the movement of heat is more rapid in green timber and, as wood is usually more or less green when subjected to such treatments, the disadvantage of poor conductivity is less marked. Dry wood conducts heat much more slowly than green timber of the same species because in the latter the cell cavities are filled with sap, which is mainly water, and water is a much better conductor than air.

One effect of applying heat to a substance is to cause it to expand. Allowances to permit of expansion and contraction, with changes in atmospheric temperature, are made in all metal structures such as bridges, rails, and steel-work structures generally. Woody tissue also expands with heat, but timber in use tends to shrink when heated. This apparent contradiction is easily explained. Timber in use always contains a varying quantity of moisture in the cell walls which, on being heated, is lost to the atmosphere and, as has been previously explained, loss of moisture is accompanied by shrinkage. In consequence, although heat would cause the cell walls to expand, the loss of moisture from the walls results in shrinkage, which more than counteracts any increase in volume due to the expansion of the woody tissue. This is not so much because the expansion of wood substance is low as that shrinkage is high ; actually, in linear expansion along the grain, ash is almost identical with cast iron and steel, although the linear expansion of most other species is considerably less ; across the grain, the linear expansion of beech is about six times as great as that of iron or steel.

The reaction of timber to heat has an important bearing on its suitability as a fire-resistant material. Because of the relatively high specific heat and poor conductivity of wood, wooden doors are frequently more effective in preventing the spread of a fire in a building, than those made of steel, or other materials. Wooden doors fail when shrinkage causes the different parts, *e.g.*, panels, styles, and mouldings, to pull apart, leaving gaps through which flames can penetrate. Failure through shrinkage usually causes a breakdown of wooden doors long before the flames have been able to penetrate by combustion, or heat by conduction. Metal doors, on the other hand, conduct heat to the opposite side so quickly, and absorb so little heat themselves in the process, that they pass on a fire from chamber to chamber with great rapidity. Papers filed in a steel cabinet will char and burn long before those in a wooden cabinet under similar conditions. In spite of eventual failure, owing to shrinkage, it has been shown that a well-constructed wooden structure is more efficient in *retarding* the progress of a fire than most other building substances. The distinction between *retarding* and *resisting* fire is important—wood is highly combustible, but is not highly inflammable.

ELECTRICAL CONDUCTIVITY

Absolutely dry wood offers practically complete resistance to the passage of an electric current, but the presence of contained moisture renders it a partial conductor. This phenomenon is the basic principle of electric moisture meters, described on page 87. Besides the moisture content, density and species influence the electrical conductivity of wood. For example, lignum vitae, and certain other dense woods, have been used for insulation purposes, sometimes being impregnated with wax to keep out moisture, thereby maintaining their insulating properties.

ACOUSTIC PROPERTIES

The acoustic properties of wood are of importance in musical instruments and in building construction.

The laws of acoustics indicate that the power of conducting or cutting sound is linked with electricity. Thus a piece of wood, so fixed as to be allowed to vibrate freely, will emit a sound when struck, the pitch of which will depend on the natural frequency of vibration of the piece. This in turn is governed by the density (since density affects elasticity) and dimensions of the piece. Wood, the elasticity of which has been destroyed, as for instance by fungal decay, will give a dull sound when tapped, in contrast to the clear ring of sound wood.

The property of resonance or of vibrating in sympathy with sound waves, is also possessed by wood by virtue of its elastic properties. The special quality imparted to notes emitted by wood is very pleasing and causes wood to be extensively used in sounding-boards and other parts of musical instruments. Uniformity of texture, which comes from extreme regularity in growth throughout the life of the tree, and freedom from defects, are the essential properties of timber for sounding-boards. Slow-grown spruce, from restricted areas in Czechoslovakia, is perhaps the most famous source of supply of high-grade piano and violin sounding-boards. More recently balsa has come into prominence for the construction of amplifying chambers of gramophones.

The ability of a material to absorb sound depends partly on the way in which it is fixed, and is partly a property of the surface. The cellular nature of wood is such that when timber is fixed so that it cannot easily vibrate, the surface has a deadening effect on sound waves ; for this reason wood is valued as a flooring and paving material.

THE HEAT VALUE OF WOOD

Like other organic materials wood is combustible ; under suitable conditions it will burn, and its constituents undergo

oxidation with the liberation of energy in the form of heat. The fuel value of a timber depends largely on the amount of wood substance in a given volume, *i.e.*, on the density, and on the chemical composition of the wood substance, and on the state of dryness of the wood. As a general rule the denser the timber the higher its potential fuel value, but this may be modified by the presence in the wood of such substances as resin. The fuel value of resin is about twice that of wood substance, and other things being equal, resinous woods have a higher fuel value than non-resinous timbers. The influence of moisture content will readily be understood; wet wood has a much lower heating value than dry wood of the same species, because much heat is lost in transforming the contained moisture into steam. It is, therefore, anything but economical to use damp firewood: it lasts longer but gives out much less total heat than the same amount of seasoned wood, even on a dry-weight basis.

Another factor influencing the value of wood as a fuel is the ash content. Although this may not affect the heating value to an appreciable extent, for certain commercial purposes the amount of residual ash is an important consideration.

Dense woods burn more slowly, and with less flame, than light woods which tend to flare up and burn away quickly. Decayed wood has, of course, a much lower heating value than the same volume of sound wood of the same species. Comparison of relative fuel values of different species presents considerable difficulties, partly because subsidiary merits such as even, regular burning qualities, and low ash content, are not easily assessed, and partly because the volumetric unit of measurement of firewood—the cord—is capable of wide fluctuations in the actual amount of contained timber, or, in effect, of combustible material. The form of wood, *i.e.*, split billets, logs, or sawn waste, and the method of stacking, result in considerable differences in the fuel value of different cords of wood of the same species. Comparison with other fuels should be on a dry-weight basis, but even

this precaution does not take into consideration the legitimate charge against wood fuel of higher costs for storage and handling of the more bulky commodity. On a dry-weight basis, the heating value of coal is about 1·6 times as great as an equivalent weight of wood, and this figure may be of some value for approximate comparisons.

PART IV

CONSIDERATIONS INFLUENCING THE UTILIZATION OF WOOD

CHAPTER X

THE SEASONING OF WOOD

THE OBJECT OF SEASONING TIMBER

SEASONED timber is admitted on all sides to be superior in general use to unseasoned material, but the real reasons for the superiority are not always appreciated. It is generally realized that dryness has something to do with the superiority of seasoned timber, but it is also frequently supposed that seasoning is a maturing process which is closely dependent on the time factor. Next to dryness the most commonly acclaimed property of seasoned timber is its ability not to "work". This we have seen from the discussion of the moisture content of seasoned timber is not strictly true.

The primary object of seasoning is to render timber as stable as possible after manufacture. A second advantage of seasoning is the reduced risk of fungal and insect attack. The growth of most wood-rotting and all sap-stain fungi ceases in wood below 20 per cent. moisture content, and several, although not all, insect pests can only live in green timber. A third advantage is the reduction in weight which accompanies loss of moisture; this is of practical importance as it reduces handling costs, and may effect economies in freight charges. The latter applies particularly to inland transport, either rail or road, and has led, for example, to cedar shingles being sold in Canada on a moisture-content basis. Further, seasoning prepares timber for various "finishing" processes, *e.g.*, painting and polishing, and it is an essential preliminary if good penetration of wood preservatives is sought. Finally, some strength properties

increase as timber dries and, although the increases may not in themselves justify the expense of seasoning, they are of more than academic significance.

PRINCIPLES OF SEASONING

Experience has shown that the chief difficulty to be overcome in seasoning timber is the tendency of the outer layers of a piece of wood to dry out more rapidly than the interior. If these layers are allowed to dry much below the fibre saturation point, while the interior is still saturated, stresses are set up, because the shrinkage of the outer layers is restricted. The stresses may attain such magnitude that the tissues of the wood are actually ruptured, and splits or checks result. The whole art of successful seasoning lies in maintaining a balance between the evaporation of water from the surface of timber and the outward movement of water from the interior of the wood. Three factors control these processes : the humidity, circulation, and temperature, of the surrounding air. The temperature has a twofold effect : by influencing the relative humidity of the air it governs the rate of evaporation of water from the surface of the wood, and by influencing the temperature of the wood it governs the rate of movement of water outwards.

Let us see how these three factors interact. The rate of loss of moisture from wood depends on the humidity of the air in immediate contact with the surface layers, and on the dryness of the layers themselves. The rate of movement of water in wood is dependent on the differences in moisture content of successive layers not being too great. If the outer layers are appreciably drier than the interior greater resistance is offered to the movement of moisture outwards than when the differences in moisture content of successive layers are less. As the air absorbs moisture its relative humidity increases and its affinity for further moisture decreases ; this slows up the drying of the surface layers. Moreover, when the air is absorbing moisture less rapidly the differences in

moisture content of successive layers of wood will be less marked, and the two factors thus combine to reduce seasoning stresses to a minimum. On the other hand, if the air in contact with the surface layers of the timber is in constant circulation its relative humidity may never become sufficiently high to retard the rate of absorption of moisture from these layers, while they, by drying out too quickly, offer greater resistance to the movement of moisture from the interior of the wood, and conditions of maximum stress in the outer layers result.

METHODS

Preliminary Seasoning.—Seasoning is sometimes begun before the tree is felled by **girdling** the trunk, *i.e.*, cutting away a strip of bark and wood completely encircling the stem. This is the general practice with teak in Burma, the main purpose being to reduce the weight of the timber so that logs will float. The girdle severs the supply of water from the roots, while before they die, the leaves exhaust a considerable amount of the water present in the trunk.

Timber is sometimes purposely stored in log form to effect preliminary seasoning, although more often than not log storage is a matter of convenience in connection with the maintenance of timber supplies to a mill. In point of fact the loss of moisture from timber in the log is extremely slow, and for practical purposes seasoning may be said to begin after conversion. There is, however, another aspect of log storage which may be of some practical significance. The parenchymatous tissue in the sapwood remains alive after the tree is felled, until the moisture content of the wood falls below the minimum necessary to sustain life, or until the food material in the cells is consumed. By remaining alive, the parenchymatous tissue uses up the food material which is essential to sap-stain fungi and certain insects, rendering the timber immune to infection from these sources.

Two methods of seasoning are in common use: **air,** sometimes called *natural*, and **kiln**, often called *artificial*,

seasoning, although in commercial practice a combination of the two will often be the most satisfactory and economical. So-called "**water seasoning**" is a misnomer: there can be no loss of moisture so long as timber remains water logged. All that can be said for "water seasoning" is that it may reduce the hygroscopicity of wood and its subsequent shrinkage, but the benefits are not of sufficient magnitude to be of any commercial value.

Air Seasoning.—Air seasoning aims at making the best use of climatic factors, *i.e.*, wind, sun, and rain. Wind, by circulating the air, prevents it from becoming saturated by absorption of moisture from seasoning timber, and the sun, by raising the temperature of the air, lowers its relative humidity. The combined effect of these two factors is to maintain the drying power of the air in an efficient condition. Rain, on the other hand, increases the humidity of the atmosphere and, as it is accompanied by lower temperatures, reduces the drying power of the air. As a general rule the problem is to accelerate air circulation adequately, although in the tropics, and with timbers prone to develop seasoning defects, the reverse may sometimes be necessary.

Control of the climatic factors is best achieved in properly constructed, well-ventilated sheds, but in most cases such structures are impracticable on economic grounds. The most efficient shed is, moreover, only effective up to a point: even in weather-proof buildings the relative humidity of the air varies appreciably at different seasons of the year. Control of air circulation, whether in sheds or in the open, is effected by piling the timber in properly constructed stacks, the design of which is the most important consideration in air seasoning. Control of the movement of water in wood is more difficult. It is, of course, affected indirectly by the control of air circulation, but additional measures are advisable to compensate for the more rapid movement of moisture along the grain than takes place across it. If the loss of moisture from the ends is not checked serious stresses are set up which result in bad end-splitting, and to minimize this

trouble some form of end covering should be adopted. It will be seen, then, that three factors are available for regulating air seasoning; namely, seasoning sheds, correct piling, and end protection.

Seasoning Sheds.—In its simplest form a seasoning shed may be nothing more elaborate than a large Dutch barn with a temporary roofing. On the other hand, it may be a permanent building consisting of a roof and four walls, the walls being louvred, so that air circulation through the building can be regulated with considerable precision. For softwoods, except of the very highest grades, any form of seasoning shed is likely to be prohibitive in cost, but for the more valuable hardwoods seasoning sheds should be regarded as essential, and a more or less permanent building with a corrugated iron roof may often prove more economical in the long run than a purely temporary structure. In tropical countries some form of shed is very necessary to protect timber against heavy rain and the very strong sun, but owing to the intense heat in the middle of the day a corrugated iron roof should be avoided, thatch or rough boarding is better.

Piling.—Piling technique is the most important factor in air seasoning, because such points as the position and orientation of stacks, and their method of construction, largely govern air circulation.

The site of the seasoning yard is usually dictated by such circumstances as the necessity for proximity to the saw mill, the land available, or the layout of existing buildings. Wherever possible, however, the site should be a naturally well-drained one, sufficiently removed from buildings to guard against the accumulation of stagnant air and air eddies.

The nature of the floor of seasoning sheds or yards is important. The most satisfactory is a good concrete floor which will not hold moisture, and can be kept clean. A cheaper alternative is well-rammed earth (clay) or cinders. Sawdust is bad as it holds moisture, and results in the circulating air being damp, so that seasoning is retarded, and the development of wood-rotting fungi is encouraged. The

floor must be kept clear of rubbish ; wood waste left lying about provides opportunities for fungi and insects to breed and spread to sound timber, and such rubbish increases the fire hazard. All wood waste should be collected and burned ; it is not sufficient to collect and dump it in an unused corner of the yard where it will be equally effective as a breeding-ground, if not so great a fire hazard. The important points in stack building are the orientation, foundations, spacing, and width of stacks, and the spacing and width of stickers.[1] Two alternative methods of orientating stacks with reference to the passage ways are possible ; **endwise,** *i.e.*, with the timber at right angles to the passage ways, and **sidewise,** *i.e.*, with the timber parallel to the passages. Endwise piling makes for ease of inspection and tallying of the stock, but sidewise piling ensures better air circulation from the passage ways. In endwise piling the air is held up by the stickers and can only pass by way of the narrow alleys between stacks. Economic considerations, and mill layout, however, usually determine the method selected, but where mechanical elevators are used for stack-building sidewise piling is obligatory. If several varieties of timber, requiring different seasoning periods, are dealt with in the same yard, sidewise piling is more convenient and economical. High handling costs result when one of a series of endwise-piled stacks is required out of turn, because turning space is at a premium, and timber coming out at right angles to the extraction ways involves loss of time in manœuvring.

For the foundations of stacks baulks of timber are commonly used, but concrete, brick, or even wooden piers, are better, as they offer less resistance to the free circulation of air under a stack. If solid baulks are used they should be at right angles to the alleys. Wood in the foundations should be thoroughly sound and well-seasoned, and should be treated with creosote or other wood preservative. The height of the foundations should be governed by the nature of the floor : a height of 8 to 12 in. is sufficient with concrete

[1] See page 113.

floors, but not less than 18 in. is desirable with earth floors. The foundations of open-air stacks should be sloped to permit of rain running off the top boards instead of soaking into the timber.

Unless solid baulks at right angles to the length of the stack are used, a system of bearers and cross stringers is necessary. For this purpose metal rails are best as they interfere with air circulation least ; they should be at right angles to the length of the stack and should be covered with strips of wood to prevent the bottom layer of timber from coming in contact with the metal. If the stack is to be a large one, it is important to distribute the weight evenly over the foundations. This can be achieved by means of a system of bearers and strips at right angles to the rails.

The dimensions of stacks must be kept within certain limits to secure rapid and uniform drying, and to avoid the risk of stagnant air accumulating in the centre of the pile : a cause of unequal drying and sometimes leading to fungal infection. Twelve feet is recommended as the maximum width for stacks, and 2 ft. as the minimum width of passage ways. Excessive height is to be avoided for similar reasons, and there is the added disadvantage that tall stacks increase handling charges. Sixteen feet is suggested as a reasonable maximum, but unless mechanical elevators are used, or the calls on the yard space are particularly pressing, a stack should be under rather than over this height.

In practice the nature of the output of a mill often determines the size of stacks. Where the output is varied in species and sizes the stocks carried of any particular grade are probably sufficiently small to impose reasonable limitations on the size of stacks. On the other hand, a large mill confining itself to a single, or at the most, two or three grades, will have to arrange to distribute the out-turn in stacks of suitable dimensions.

Circulation of air through a stack is secured by separating the successive layers of timber by strips of wood known as **stickers**, the thickness of which regulates the rate of air flow.

The stickers should be of sound, seasoned timber and, to avoid indentation of the boards in the lower part of the pile, not of a harder type than the timber in the stack. The use of softwoods for this purpose is a safeguard against the introduction of *Lyctus* beetles through infected stickers. When a stack is dismantled the stickers should receive as much consideration as is given to the seasoned timber; they should be collected, bundled, and stored for further use.

The thickness of stickers depends on the thickness of the timber to be seasoned, and its drying qualities. For thin stock, of species not subject to serious degrade in seasoning, 1½ in. stickers are suitable, but thick planks of species which are inclined to split or surface-check badly may require stickers as thin as ½ in. To secure rapid drying, the thickest stickers that experience has shown can be used with safety, should always be employed. Stickers should be no wider than is absolutely necessary, as the area of timber in contact with them is hindered from drying at the same rate as the remainder, and in certain timbers, may become stained. Too narrow stickers, on the other hand, cause indentation and, for this reason, the width should never be less than the thickness, and for really soft timbers it may need to be more. A maximum of 2 in. should, however, suffice for the most easily bruised timber.

The stickers at the ends of a stack should be wider than the remainder and should project about ½ in. beyond the ends of the stacks. By this means a buffer is provided against the rapid circulation of air over the ends of the timber, and a considerable amount of end-splitting is prevented. Furthermore, stickers should project slightly beyond the sides of sidewise-piled stacks to protect the timber from being bumped by traffic in the passage ways.

The distance between stickers depends on the thickness of the stock and its liability to warp; ½ in. boards require stickers 2 to 4 ft. apart, but planks of 2 in. and upwards are sufficiently supported by stickers 6 to 8 ft. apart. Stickers impede the circulation of air and, therefore, should not be

unnecessarily numerous ; on the other hand, an insufficiency of stickers results in the sagging of boards and planks. If the distance between the stickers is less than the width of span between the foundation piers or baulks a system of stringers and bearers is necessary.

Fig. 82 illustrates the important details of stack construction. It may be observed that the stickers are in vertical rows, and this arrangement is essential to avoid unequal stresses on the lower layers of timber which inevitably result in a considerable amount of bowing. (See also Fig. 83.) As far as possible the timbers in a stack should be of uniform length, and when this is not practicable the longest pieces should be at the bottom, and the projecting ends must be supported as in Fig. 82. Further, in any one row, all pieces must be of the same thickness, otherwise the thicker pieces carry the weight of the whole stack above them. Other points in stack construction are that the top layer of timber, and all projecting ends, should be covered with thin, dry boards, or, if in an open yard, by a raised roof ; that thin, dimensional stock, should be weighted by laying heavy baulks of seasoned timber on the top of the stacks, to prevent bowing and cupping. Timber should be stacked with stickers as soon after sawing as possible ; **close piling,** *i.e.*, without stickers, even for a few days, is a fruitful cause of staining.

A special form of piling, often adopted for hardwoods in England and in certain continental countries, is illustrated in Fig. 83. In this method each board is piled in sequence as cut, and the log is sold as a unit. The advantages claimed for this method of piling are that the merchant is not left with narrow widths and defective boards, and, with figured woods, " matched " material is kept together.

Timbers liable to discolouration, *e.g.*, sycamore, are frequently seasoned by stacking on end, thereby avoiding the use of stickers ; and baulks, sleepers, squares, etc., are usually " self-piled " in various ways, the essential feature of which is that some of the pieces of timber act as stickers.

Air Seasoning of Timber

Points illustrated by the stack

1. Level foundations which raise the pile well off the ground.
2. Stack not more than 6 ft. wide.
3. Piling sticks in vertical lines and the support of short lengths and overhanging pieces.
4. Weather-tight sectioned roof.
5. 2 in. oak with ½ in. sticks to reduce rate of drying and prevent checking.
6. 2 in. beech with flush stickers, overhanging stickers and coatings to reduce end-checking.
7. Method of building sample board into pile.
8. Piling of sleepers and large-sectioned stock of free-drying timber for rapid seasoning.
9. Squares piled in stick and self-crossed.

" **Self-piling** " is a common practice with softwood timbers in Scandinavian countries, and when this method is used for boards stacked flat it is obviously inferior to piling with proper stickers. But planks are frequently piled on their narrow face, the distance between the rows being the width of the planks, *i.e.* one row of planks is laid flat, the next on their narrow faces, and the succeeding row flat, and so on. In this way the distance between the rows may be 6, 7, 8, or 9 in., and if the planks are only 2 to 3 in. thick a relatively small area of timber in the stack is covered up by other green material. Such an arrangement ensures rapid drying of the surface of the timber, a very necessary condition if " blue stain " is to be avoided in Baltic pine, but it is too drastic for many timbers and would give rise to serious surface-checking.

End Protection.—End protection is provided by coatings of various, more or less waterproof substances, or by strips of wood or metal nailed to the ends of timber. Strips of wood are thoroughly bad for the purpose, because the small longitudinal shrinkage of the strip is opposed to the much

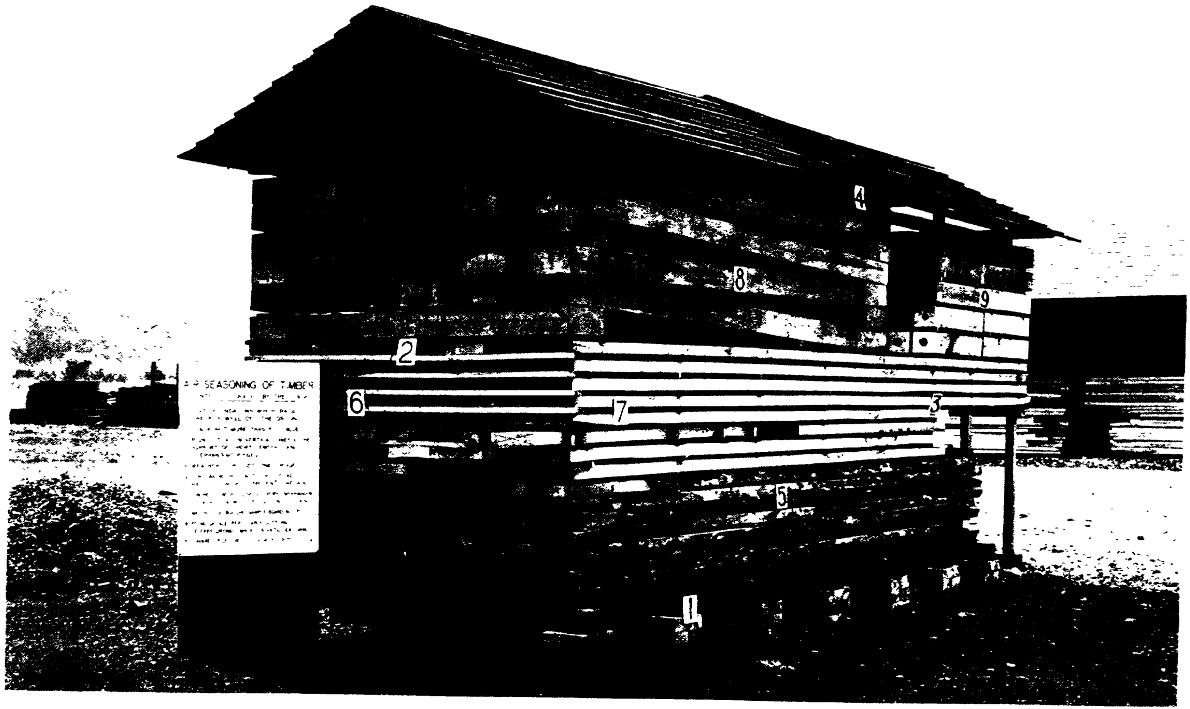


FIG. 82.—STACK showing the various points of good piling technique. (See opposite page.)

Photo by F.P.R.L., Princes Risborough.

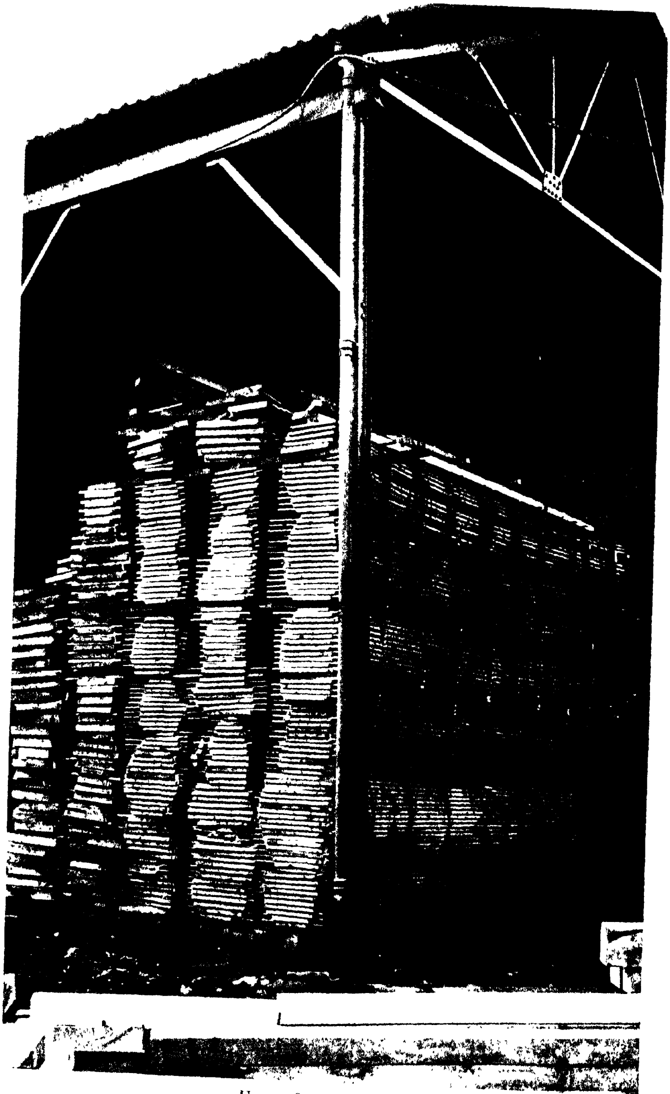


Fig. 83.—Log Piling.

Photo by F.P.R.L., Princes Risborough.

greater shrinkage of the timber, with the result that shrinkage is restricted between the points of attachment of the strip, and end-splits frequently develop in the timber. If end protection is provided by a thin strip of metal, *e.g.*, hoop iron, the metal buckles concertina-fashion as the baulk shrinks and end-splitting may be avoided. A more satisfactory method, however, is the use of an **end-coating,** the essential qualities of which are impermeability to water and air, a semi-liquid state to permit of its being applied with a brush, and a capacity to harden on exposure so that it will set and not flake off when the timber is roughly handled. Many substances and mixtures fulfil these conditions so that choice is mainly one of expediency. Wax is an obvious possibility, but cost and the necessity of having to apply it hot make it unsuitable. The United States Forest Products Laboratory recommends a mixture of one part asbestine and one part barytes to two parts of hardened gloss oil; a gallon of the preparation being sufficient for 100 square feet. A very successful mixture consists of finely powdered, unburnt brick clay and ground dammar (a resin compound soluble in petroleum spirits) in equal proportions, with sufficient paraffin to permit of spreading the mixture. The proportions of clay may be increased to about 55 per cent. to reduce the cost of the preparation. Clay or chalk mixed with dung, as a spreading medium, has also been used, but fine mud without a binding medium flakes off too easily to be of value. Sheets of plywood nailed over the ends of a stack are a cheap compromise, but they interfere with the circulation of air along the stack and may slow down the seasoning process too drastically.

Kiln Drying.—Kiln drying is effected in a closed chamber which admits of the maximum control of air circulation, humidity, and temperature. In consequence, drying can be regulated so that shrinkage occurs with the minimum of degrade, and lower moisture contents can be reached than are possible with air seasoning. The great advantages of kiln seasoning are its rapidity, adaptability, and precision.

Moreover, the temperatures used in any kiln-drying process are lethal to insects and fungi, so that a sterilizing treatment is provided in addition to seasoning. On the other hand, errors in technique magnify seasoning defects and may result in serious damage to the timber. It is necessary to regulate the process to suit circumstances: different timbers and dimensions of stock require drying at different rates. As a general rule softwoods can withstand more drastic drying conditions than hardwoods, thin boards than thick planks, and partially dry stock than green timber. In practice a standard schedule is often applied, irrespective of the species, dimensions, or conditions of the timber. This may result in serious damage to the timber, giving the method a bad name, whereas extensive tests show that, if properly carried out, kiln drying is as successful as air seasoning.

A kiln consists of some form of more or less air-tight shed, fitted with heating apparatus, a supply of water or steam, and, in some types of kilns, artificial means of accelerating air circulation. One of the greatest problems in kiln construction is the reduction of heat losses to a minimum. To this end cavity walls of brick or tile are generally used, and the interior surfaces are painted with some waterproofing substance. The doors are of wood or metal of several designs which aim at securing a tight fit.

The usual method of supplying heat to kilns is by a system of steam-heated coils over which the air passes before circulating through the stacks of timber. Other methods of heating could be used but steam is particularly suitable as it is easily regulated, and in many sawmills it is available free from the burning of wood waste. The humidity of the air can be controlled by regulating the temperature, or by admitting water or water vapour. In practice the manipulation of temperature alone is not sufficient, and a system of water or steam sprays is installed. The circulation of air is secured by "**natural-draught**" or mechanical means. The former method is dependent on temperature differences at different levels in the kiln which cause air currents to be set

up. **Forced circulation** is obtained by means of fans or blowers. Natural draught circulation is sometimes further stimulated by the suitable arrangement of the steam or water sprays.

In theory the air in a kiln can be used indefinitely, if there is some means of de-humidifying it after it has passed through the timber. In practice some of the moisture is removed from the air by condensation on the walls of the kiln, but it is usual to arrange for a portion of the moisture-laden air to be drawn off and replaced by an equivalent amount of fresh air from the outside. The escape of used, humid air and the introduction of fresh, relatively dry air is usually designed to take place through special outlet and inlet channels, but a certain amount of interchange occurs as a result of natural leakage.

The rate of drying in different parts of a kiln varies, because the temperature of the air and its absolute humidity vary at different levels, and arrangements have to be made to counteract this as far as possible. One method is to increase the rate of circulation, so that there is less opportunity for the air to become saturated before it has passed through the timber. Where artificial means of accelerating air circulation are not installed the same effect can be obtained by keeping down the size of the stacks of timber, or alternatively, the direction of circulation may be reversed by means of a double set of outlet and inlet ports, coils, and sprays.

It is important to follow the conditions of the air in the kiln closely during a run, and by means of wet and dry bulb thermometers both temperature and humidity can be kept under observation. Precautions are necessary to ensure that the instruments give a correct picture of the conditions in the kiln: two or three hygrometers should be used, and each must be at least 6 in. from any wall so that it is in the path of the main air-flow.

Type of Kiln.—There are two main types of timber-drying kilns, namely, **progressive** and **compartment** kilns: the former are almost always operated by the "natural-

draught " method, and the latter may be natural- or " forced-draught " operated.

Progressive Kilns.—In progressive kilns green timber is admitted at one end and moved gradually to the other, where it emerges dry. The air flows in the opposite direction to the movement of the timber, so that the material that has been longest in the kiln receives the hottest and driest air. In passing through the piles of timber the air absorbs moisture which increases its relative humidity and lowers its temperature, so that at the loading end the wet timber comes in contact with relatively cool, humid air. The severest drying conditions are, therefore, at the exit end where the timber is best able to accommodate itself to them, and the mildest at the loading end where the timber is least able to stand up to rapid drying. After circulation through the length of the kiln part of the air is discharged into the atmosphere, and the remainder returns along the floor of the kiln to be re-circulated. Fresh air is admitted at suitable openings to compensate for the amount discharged and this, mixed with the returning cool air, is heated prior to circulation through the timber. Fig. 84 illustrates the principal points in the design and mode of operation of a natural draught progressive kiln.

The uses of progressive kilns are limited since their successful operation depends on a steady supply of timber of the same species and dimensions. The reason for this is that the drying conditions cannot be modified as each new load is added, and while the kiln still contains partially dried loads of a particular type. In addition to lack of flexibility, progressive kilns cannot be regulated with great precision, and this renders them unsuitable for timbers that are difficult to season. Further, as the main air-flow is longitudinal the timber should be piled at right angles to the length of the kiln (to ensure uniform drying) and this restricts progressive kilns to short stock unless kilns of great width are to be provided. The advantages of the progressive kiln are held to be that once placed in efficient operation they require less skill to run, and the output is more or less continuous.

Compartment Kilns.—As the name implies, compartment kilns consist of a compartment or building in which the timber is placed, and in which it remains without change of position until it is seasoned. Such kilns may be operated by the natural- or forced-draught methods. The air may be circulated cross-wise from top to bottom of the kiln, or *vice versa*, or from end to end; and the circulation may be reversible. The timber may be stacked on edge, when the main circulation is usually up through the stack and down the sides of the kiln; or lying flat, when the circulation is up one side, across the stack, and down the other side. Flat piling, the more common method, is sometimes arranged with a central flue, the air travelling up the flue and circulating to either side.

Conditions at the commencement of a run are mild; that is, the relative humidity of the air in circulation is high and its temperature is low. As drying proceeds the temperature is raised and the humidity is reduced, and, as a result, the drying conditions become more severe, but are kept within bounds to prevent degrade of the timber.

The great merit of compartment kilns is their flexibility, coupled with the fact that they can be designed to give precision of control. Flexibility is desirable when the outturn of a mill is constantly changing, both in species and dimensions of stock; and maximum control of drying conditions is essential for the successful drying of difficult timbers. In both these circumstances compartment kilns are much to be preferred to progressive kilns.

Fig. 85 is an example of the **natural-circulation kiln** with a central flue in which the steam-jet humidifiers assist air circulation to some extent. Fresh air is admitted in the basement, and after passing over heating coils, circulates *via* grids running the length of the kiln between the stacks of timber. The air is humidified at the floor level and it then rises, passing through both stacks to fall between the timber and the walls of the kiln. Some of the used air escapes at floor level *via* the chimneys, and the remainder falls to the

basement where it mixes with fresh air before re-circulation.

This particular type of compartment kiln is not suitable for very wet timber : the circulation is slow and uncertain, and it is difficult to regulate, but the kiln is simple to construct, and there is little to get out of order, and it can be made reasonably economical in heat and steam. It is suitable for drying partially-seasoned stock, and for re-drying stock that has taken up moisture in the course of manufacture.

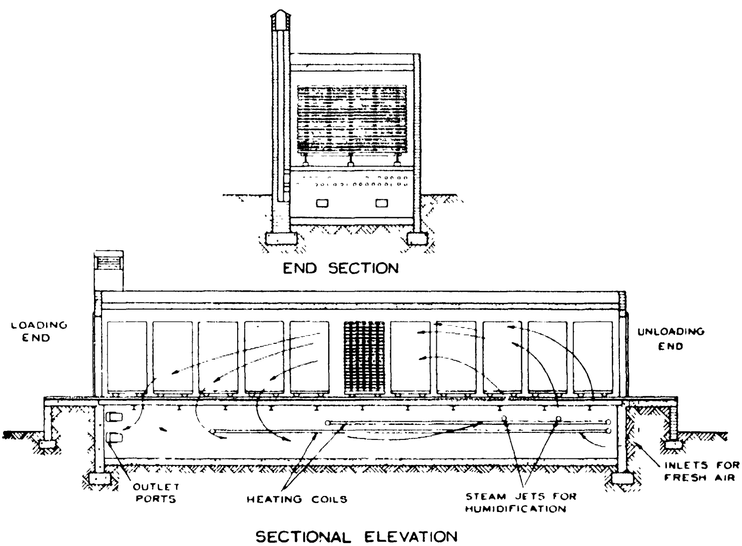


FIG. 84.—PROGRESSIVE KILN.

By courtesy of the Director, F.P.R.L., Princes Risborough.

Modifications of design of natural-draught kilns have been evolved with a view to improving air circulation and providing facilities for more precise control. For example, kilns are sometimes fitted with cooling pipes through which cold water circulates. These pipes condense the moisture absorbed from the timber by the circulating air. Another type of kiln is the **water-spray compartment kiln** designed by Mr. H. D. Tiemann of the U.S. Forest Products Laboratory. In this type, water sprays are arranged in rows along the side walls of the kiln and heated air passes through them, and is

cooled in the process until it reaches a state of saturation. The saturated air is then re-heated before circulation through the timber. In this way the condition of the air in circulation can be precisely controlled, but such kilns are complicated in design and operation, and they require considerable heat and water supply.

Forced-draught kilns may be of the **external-** or **internal-fan** type. In the external-fan kiln the air is heated, humidi-

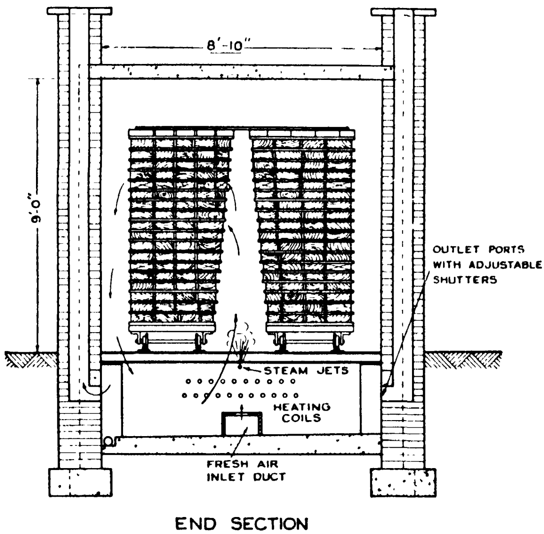


FIG. 85.—NATURAL-DRAUGHT COMPARTMENT KILN.

By courtesy of the Director, F.P.R.L., Princes Risborough.

fied, and set in motion by apparatus located outside the kiln, whereas in the internal-fan type the heating, humidifying, and circulating apparatus is situated inside the kiln, either in the roof or basement. Fig. 88 is an example of an internal-fan kiln, the design of which has been evolved at the Forest Products Research Laboratory, Princes Risborough. The fans, heating coils, steam sprays, and used air outlets, are situated in the roof, and the fresh air is admitted at floor level. It is claimed that this type of kiln probably offers more uniform air circulation than any yet designed, and it

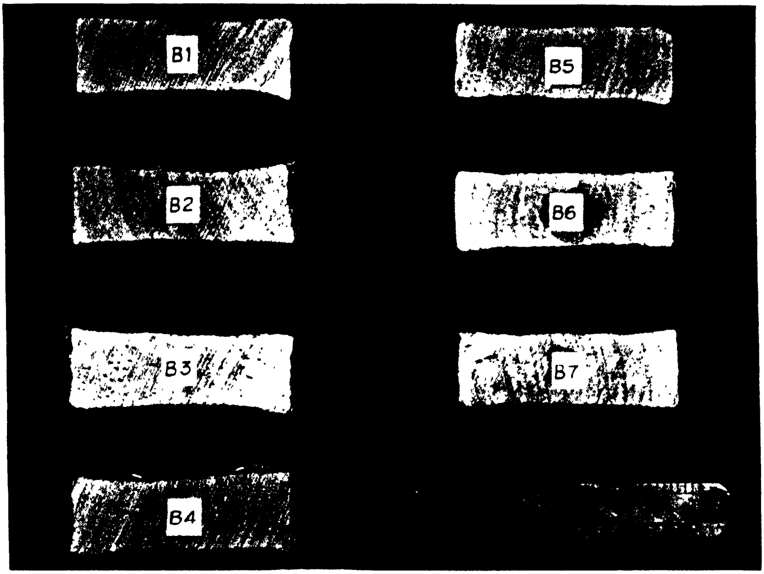
provides the maximum timber accommodation for a minimum of equipment, but it requires more head room than the basement type of kiln.

The external-fan kiln is more compact than the internal-fan type, and the regulating apparatus is particularly accessible, but the air is admitted and withdrawn at the same point, so that unless baffles and dampers are carefully arranged there is a risk of the air circulation short circuiting.

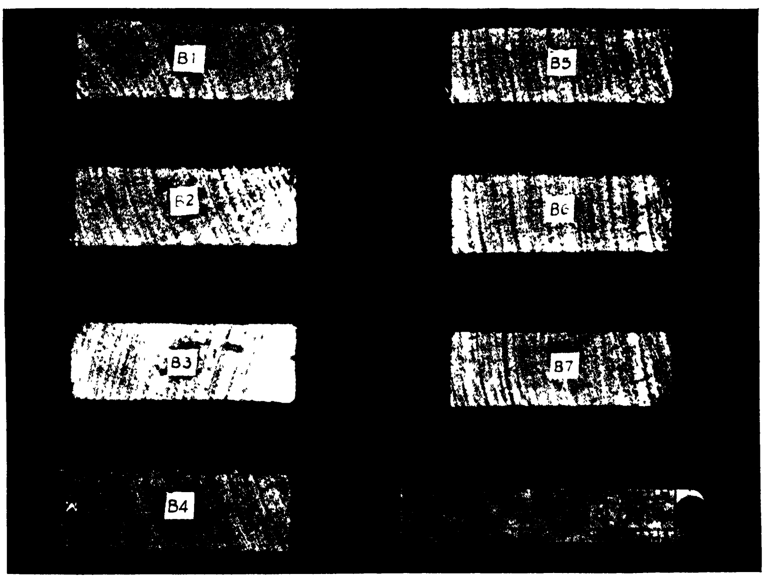
Forced-draught compartment kilns have the great merit of adaptibility to any kind, or conditions of timber, and they can be regulated with precision to suit all circumstances. On the other hand, they are more costly to build, and complicated to construct and operate, than natural-draught kilns.

Choice of Kiln.—The primary conditions determining the choice of the type of kiln to be installed depend on such points as first cost, the output of timber, the space available for the kiln, the condition of the timber to be dried (*i.e.*, whether green or partially or fully air-dry), and the kind of timber. The progressive kiln is, we have seen, suitable only for one type of output and is, therefore, restricted in use. Natural-draught compartment kilns are slower in operation than forced-draught kilns, and they are inclined to be unsatisfactory as regards air circulation, but they are the lowest in first cost. They are adequate for dealing with partially dry timber and the re-drying of manufactured stock. Forced-draught compartment kilns are more rapid and offer the maximum flexibility in operation, but they are more costly to install and maintain.

As kiln installation involves considerable capital expenditure, first cost should not be allowed to weigh too heavily in the selection of a particular type of kiln: a higher initial cost may justify itself by proving more economical in the long run. For example, the more expensive forced-draught kiln provides a greater out-turn per cubic foot of kiln space than the natural-draught type, and it ensures the maximum control of drying conditions. Either of these factors may well justify the higher initial cost of installation. Of the



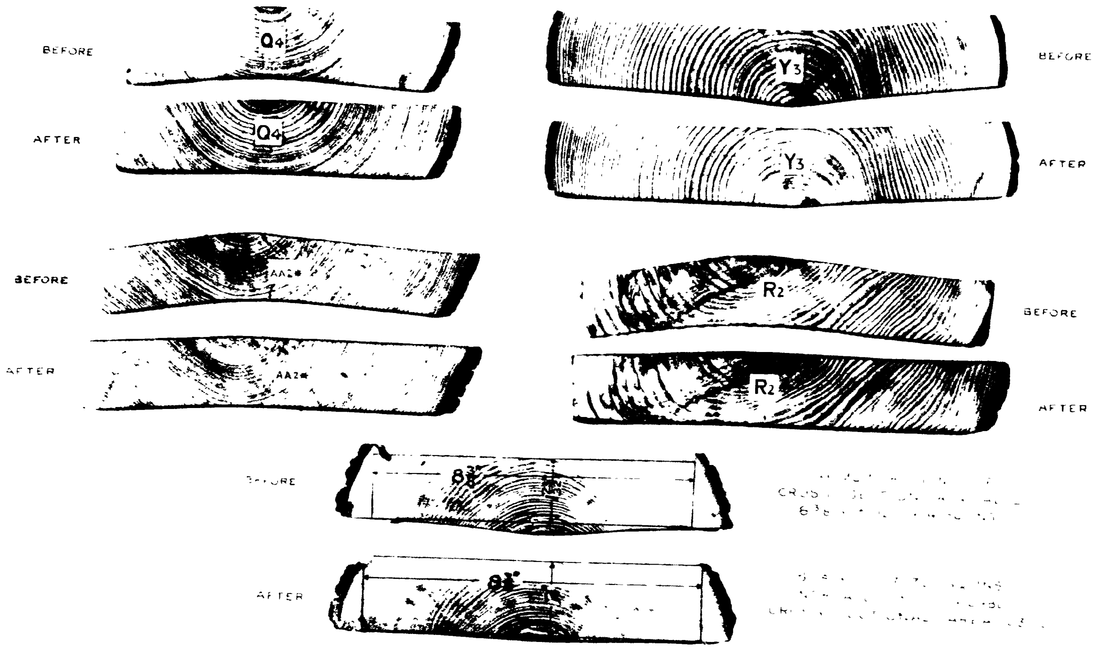
(*a*) Before treatment.



(*b*) After treatment.

FIG. 86.—RE-CONDITIONING OF COLLAPSED TASMANIAN OAK.

Photos by F P R.L., Princes Risborough.


BEFORE
AFTER
BEFORE
AFTER
BEFORE
AFTER
BEFORE
AFTER
AFTER
Q4
Q4
Y3
Y3
AA2
AA2
R2
R2

two classes of forced-draught compartment kilns, the external-fan type is the more compact, and the operating apparatus is especially accessible, but the internal-fan kiln, particularly if of the overhead variety, provides more uniform drying conditions.

COLLAPSE

Some timbers are liable to a defect known as **collapse** if kiln dried too rapidly, or at too high temperatures. Fig. 86 *a* shows a series of cross sections of timber so affected, and it will be seen that distortion is appreciable; in extreme cases the longitudinal faces may become corrugated. The defect is serious because, in addition to the loss in trimming mis-shapen timber, shrinkage is abnormally high, and the strength properties of the timber are reduced. Collapse is due to the walls of individual cells caving in, and is brought about in the following manner. Cell-wall substance is relatively plastic at high temperatures, while conditions then are favourable for the rapid dispersal of water from the cell cavities, and the tensile force of the escaping water pulls the wet cell walls together. The conditions that predispose timbers to collapse are initial high moisture content and too rapid drying at high temperatures, but some timbers are more liable to the defect than others.

A method, known as **re-conditioning,** has been evolved for eliminating collapse with complete success. It consists in heating kiln-dried stock in saturated air up to about 210° F., and maintaining the conditions for some hours before allowing the timber to cool rapidly. Fig. 86 *b* shows the effect of re-conditioning the same piece of timber, illustrated in Fig. 86 *a*. The timber is 3″ × 1″ Tasmanian oak flooring strips kiln dried to below 15 per cent. moisture content and then re-conditioned for a period of 4 hours. It was found that the moisture content of the timber was increased only by $\frac{1}{2}$ per cent. as a result of re-conditioning, and there was an appreciable gain in cross-sectional area. Slight checking occurred on the edges, but it was not sufficiently serious to be

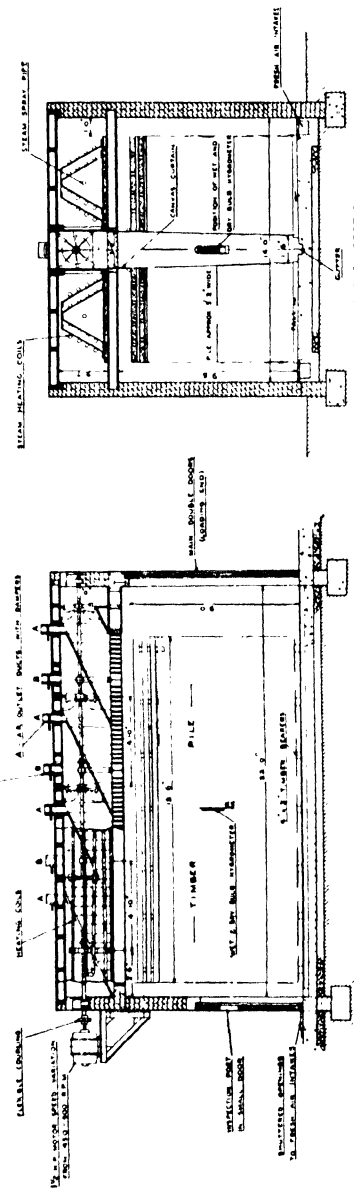


FIG. 88.—FORCED-DRAUGHT INTERNAL FAN KILN.

By courtesy of the Director, F.P.R.L., Princes Risborough.

of any commercial importance, and mechanical tests showed that the strength properties of the timber were not lowered in comparison with uncollapsed material of the same moisture content. Machining qualities were reported to be milder, and the timber worked more easily and better. Equally successful results were obtained by the same process with a consignment of elm, which in addition to collapse, was badly corrugated.

Timber that is badly warped or cupped, without showing any visible signs of collapse, may also be successfully re-conditioned. For example, some beech that was badly distorted was treated similarly to the Tasmanian oak and the re-conditioning was effective in removing much of the distortion, and it resulted in an increase of roughly 5 to 6 per cent. in cross-sectional area. Even normal shrinkage can be reduced by the "re-conditioning" process. For example, some ash was most successfully re-conditioned, although except for some cupping it had suffered little distortion in the original kiln-drying process, and the shrinkage was normal. After being "re-conditioned", however, there was an increase of 23 per cent. in available cross-sectional area compared with that of kiln-dried material that had not been re-conditioned (Fig. 87).

Re-conditioning, then, besides removing collapse, may be employed to remove distortion due to other causes, and it is also effective in reducing normal shrinkage. It is not suggested that re-conditioning should be a complement to kiln seasoning in every case, but the results obtained have been so striking that its possibilities are not without practical significance.

CHAPTER XI

DEFECTS IN TIMBER

TIMBER, being a natural product, is seldom entirely free from blemishes and other features which tend to lower its economic value ; these are spoken of collectively as **defects**. A feature which would in some circumstances be considered a blemish may, however, under different conditions enhance the appearance of wood. Defects may be classified under two broad heads : natural defects, those due to factors influencing the growing tissue of the living tree, and defects resulting from the activity of external agencies or the subsequent treatment of felled timber.

NATURAL DEFECTS

Knots are, perhaps, the commonest type of defect in timber. As the tree increases in diameter it gradually envelopes the bases of the lateral branches ; the portions of the branches enclosed within the wood of the trunk are called knots. If the branches are alive at the time of their inclusion their tissues are continuous with those of the main stem and the knots so formed are said to be **live** or **tight knots**. When a branch dies a stump remains which is gradually surrounded by the tissues of the trunk, but being dead, its tissues are not connected with enveloping tissues of the main stem, and a **loose** or **dead knot** results, which may fall out when the timber is converted. The broken stubs of dead branches provide ready access to decay and, consequently, dead knots are frequently unsound.

Knots vary in size from little more than a pin-head, to

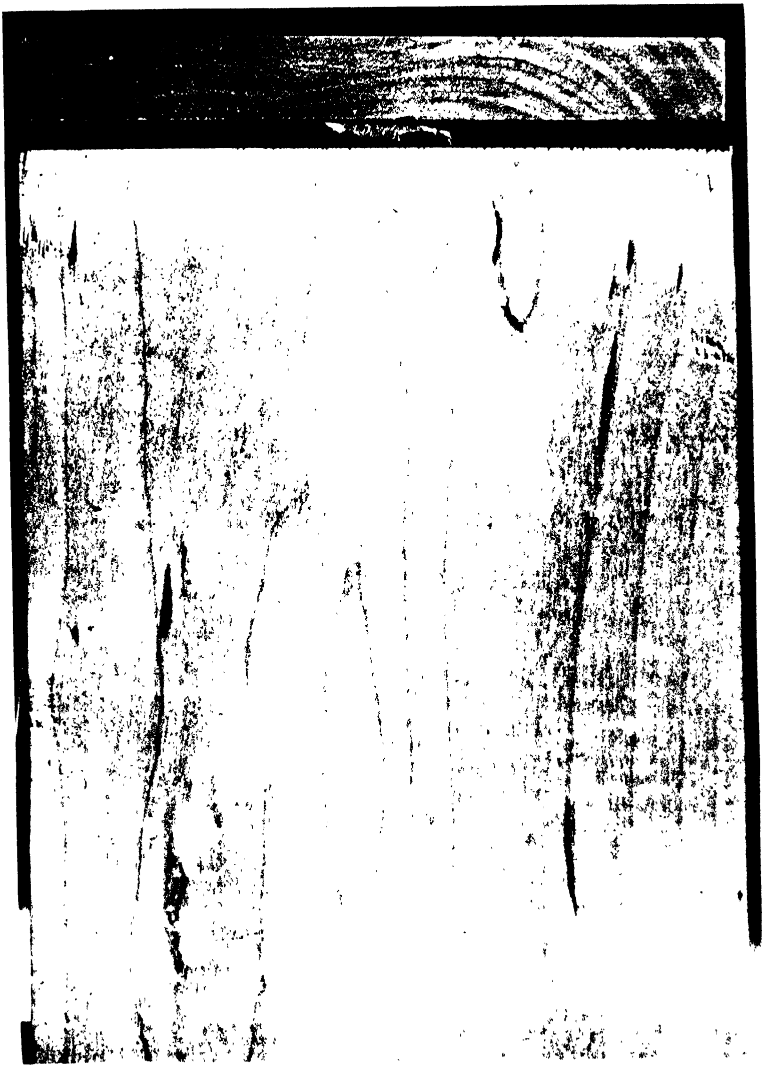


FIG. 89. PITH FLECKS IN BIRCH. The upper portion of the figure shows the appearance of pith flecks on cross section, and the lower portion their appearance on a longitudinal face.

Photo by F.P.R.L., Princes Risborough.

several inches in diameter. They also vary in shape, according to the angle at which they are cut through during conversion. A **round knot,** for example, is more or less circular in form, as seen on the face of a board, and a **spike knot** is one sawn through in a lengthwise direction. Knots have an important bearing on the utilization of timber, and in many species they are the primary cause of degrade. They may spoil the appearance of boards, and the irregularity of the grain in the region of knots reduces strength properties, besides giving rise to seasoning defects and difficulties in wood working.

Bark Pockets.—Pockets of bark are sometimes included in the wood of the main stem. They result from injury to the cambium. Growth ceases locally until the adjacent cambium has completed the occlusion of the damaged area, resulting in portions of bark becoming imbedded in the wood·

Pith Flecks.—Patches of abnormal parenchymatous tissue, called **pith flecks,** occur in some timbers, as a result of the tunnelling of the cambium by the larvae of certain insects. Pith flecks are usually wider tangentially than radially, and extend considerable distances vertically ; their inner faces follow the outline of the cambial sheath and their outer faces are irregular in outline (Fig. 89). Pith flecks are a common feature of some timbers, *e.g.*, alder, birch, maple, sycamore, but they are not sufficiently constant in occurrence to be of more than subsidiary value in identification.

Included phloem, although a normal feature of some timbers, is usually considered a defect as far as utilization is concerned. (See page 28.)

Pitch pockets are described on page 20, and illustrated in Fig. 13. In the Canadian literature they are classified according to size as *small*, *medium*, or *large*. When a pitch pocket is cut through at its widest part, so as to appear as a shallow opening on the longitudinal face of a piece of timber, it is called a **pitch blister**. **Pitch seams or shakes** are openings along the grain which follow the outline of the growth rings. (See also page 20.)

Gum veins are traumatic canals that occur in some woods ; they are usually filled with dark-coloured deposits.

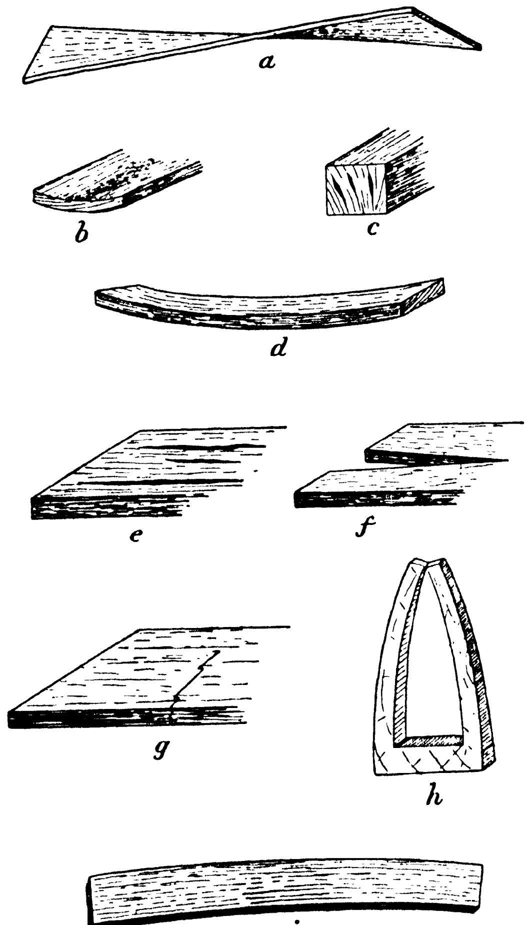


FIG. 90.—*a*, Twist ; *b*, cupping ; *c*, honeycomb checks ; *d*, bowing ; *e*, checks ; *f*, end split ; *g*, compression failure ; *h*, case-hardened board ; *i*, spring.

In some timbers, *e.g.*, jarrah, they are infrequent in occurrence and constitute a definite defect. In other timbers, *e.g.*,

Nigerian walnut, they are so frequently present as to constitute a characteristic feature of the wood, and may even enhance its appearance.

Mineral streaks are defined as " localised discolouration of timber, in the form of streaks or patches usually darker than the natural colour, which does not impair the strength of the piece ".[1] Mineral streaks have been found in sycamore and wych elm. The term has also been applied to the light-coloured streaks occurring in timbers of the family *Dipterocarpaceae*, *e.g.*, lauan, meranti, seraya, keruing, gurjun. These streaks are really the resin canals in longitudinal section, which, because of their white or yellow contents, show up against the red or brown background of the wood.

Latex canals are described on page 28, and illustrated in Fig. 43. The large canals occur in relatively few woods, *e.g.*, those of the family *Apocynaceae*, and when present cannot be treated as ordinary defects as they are a natural feature of the structure of such timbers. For some purposes, *e.g.*, as cores for veneer surfaces, and uses requiring timber in short lengths, the presence of latex canals is immaterial.

Compression failures are zigzag hair cracks that occur across the grain near the centres of some logs, *e.g.*, African mahogany, lauan, meranti (Fig. 90 *g*). It is thought that these fractures arise as a result of wind action or other external forces bending the trunk of the tree during the comparatively early years of its life. The cracks are frequently only visible when the timber is seasoned, but it has been established that the fractures are present in the standing tree. Moreover, they are often associated with the presence of " spongy heart ". Compression failures are a serious defect, rendering timber valueless for most purposes. Affected boards will often break in two when lifted, a condition which has given rise to the expressive term *three-men-boards,* the third man being required to support the timber

[1] *British Standard Terms and Definitions Applicable to Softwoods,* British Standards Institution, No. 505, 1934.

in the middle ! Other names for compression failures are *thunder-shakes*, *lightning-shakes*, and *cross-breaks*.

DEFECTS DUE TO OTHER THAN NATURAL CAUSES

Seasoning Defects.—Next to knots the commonest causes of degrade in timber are defects due to faulty seasoning. It has been explained that as wood dries it shrinks, and that the shrinkage is not uniform in all directions. Moreover, the outer layers of a piece of wood tend to dry out more rapidly than the interior, resulting in temporary or permanent distortion of the timber, and even in the separation or rupture of the tissues.

Cupping is a warping across the width of a board (Fig. 90 *b*). In flat-sawn material one surface is more nearly radial than the other, and, since radial shrinkage is less than tangential, the side towards the pith shrinks less than the other, and the board is bowed in cross section. It follows that cupping does not occur in quarter-sawn material.

Twisting is the spiral or corkscrew twisting of a board or plank in a longitudinal direction which, in extreme cases, may render the timber valueless (Fig. 90 *a*). It can usually be traced to spiral or interlocked grain, although it may also result from unequal shrinkage, due to variation in density within the board or plank.

Twisting and cupping can be reduced by using sufficient stickers and weighting the tops of stacks.

Bowing is a warping (or sagging) from end to end of a piece of timber (Fig. 90 *d*) ; that is, it is similar to cupping except that it occurs along the length of the piece and not across its width. Bowing is not uncommon in boards from near the " core " or " heart " of a log, and is the result of the sudden release of internal stresses when the log is sawn through. All timber is more or less subject to bowing, but that of certain species is more susceptible than others. Bowing may also result from too wide spacing of stickers

which causes the timber to sag under its own weight.

Spring is distortion in the longitudinal plane, the board or plank remaining flat (Fig. 90 *i*).

Checks and *splits* are separations of the wood tissues in the longitudinal plane and are distinct from the horizontal fractures, "thunder-shakes" or compression failures, that have their cause in other factors than drying stresses. A check is a separation of the fibres that does not extend through the timber from one face to another (Fig. 90 *e*), and splits are separations extending from face to face. An end split is one that occurs at the end of a log or piece of timber (Fig. 90 *f*).

Checks and splits may "close-up" if the dry timber is subsequently exposed to damp conditions, but once the fibres have separated they cannot actually join together again, and the checks and splits are present although they may not be visible.

Shakes.—Serious splits are often called "shakes", but it is better to confine the use of this term to separations of the fibres in timber of large size or in the log which may not originate from drying stresses. These are of several types, *e.g.*, **ring-shake** where the separation follows a growth ring, **star-shake** where the ruptures radiate outwards from the pith.

Case-Hardening.—When timber is dried so rapidly that the outer layers begin to shrink while the interior is still saturated a stress is set up, and the outer layers are restrained from shrinking the normal amount. This condition is known as **case-hardening,** and unless it is removed by a steaming treatment that restores moisture to the outer layers, it is liable to lead to surface checks. Case-hardening also leads to cupping and other forms of distortion when the timber is subsequently re-sawn or worked up.

Honeycombing.—If case-hardening is not relieved by steaming, the outer layers set without shrinking the normal amount, and when the interior dries below the fibre saturation point it, too, is restrained from shrinking, and interior checks may result. This condition is known as **honeycombing.**

The stresses set up are greatest tangentially because shrinkage is greatest in this direction, and the resulting separation of the fibres is always initiated where the tissues are weakest: that is, along the rays (Fig. 90 *c*).

Checks caused by case-hardening may close, and honeycombing checks may not extend to the surface, so that the defects are not always detected before the timber is worked up. A simple test for case-hardening is to cut off a cross section of a plank ½ in. along the grain and about 1 ft. or 18 in. from the end of the plank. A slot is then cut in the test sample as in Fig. 90 *h*), and the behaviour of the prongs noted. If the prongs close in the timber is case-hardened. Honeycombing can be detected by cutting a plank through about 1 foot from the end and noting whether there are any checks along the rays on the freshly exposed end.

Decay and Sap Stain.—Decay and most forms of sap stain are the result of the activity of plant organisms, called **fungi,** which feed either on the cell tissues or cell contents of higher plants. It is important to distinguish between the **wood-rotting fungi,** which are responsible for *decay* in timber, and those which merely feed on the cell contents, causing *stains*. The former remove certain constituents of the cell wall, leading to the disintegration of the wood tissues, but the latter leave the cellular structure intact, removing only the plant food materials which are contained in the cell cavities. Wood-rotting fungi seriously weaken timber, and may render it quite valueless. The **sap-stain fungi,** on the other hand, do not affect the strength properties of wood, but they spoil its appearance; sap stain is not a preliminary stage of rot, although it may indicate that, given suitable circumstances, the wood is in a receptive condition for the invasion of wood-rotting fungi.

Wood-rotting fungi belong to a large group of plants which includes mushrooms and toadstools. These latter structures are really the reproductive parts of the plant, corresponding to the flowers and fruits of higher plants. The destructive part of a fungus is its vegetable system, called

mycelium, which consists of exceedingly fine tubes or hollow threads called **hyphae.** These elongate at their tips, passing from cell to cell of the host plant, feeding on the walls in their path. The sap-stain fungi also possess a vegetative system consisting of hyphae, but their fruiting bodies are different in appearance from the familiar mushroom or toadstool.

Some fungi attack living, although probably unhealthy, trees, and others, felled timber. One condition, however, essential to the development of any fungus is the presence of sufficient moisture ; if the moisture content falls below about 20 per cent. growth cannot occur. Reduction of the moisture in wood to the critical level will cause the growth of fungi to cease, except for those which are capable of transporting moisture from an outside source and those which produce water as a result of the breaking down of cell-wall substance. Reduction in moisture content is not, however, sufficient to bring about the death of a fungus : hyphae are capable of remaining in a dormant condition for several years, resuming active growth when sufficient moisture becomes available. Kiln drying of timber, on the other hand, is lethal in its effects on hyphae, provided an adequate temperature is maintained for a sufficient period. All ordinary kiln-drying schedules fulfil these conditions. Kiln drying, however, does not remove the liability to subsequent infection, should the moisture content of the wood rise above the 20 per cent. level.

Wood-rotting fungi are of several kinds. Those that attack living trees produce the familiar "**brown rots**", "**pocket rots**", "**spongy heart**", and hollow cores, in old trees. Decay of this type may be detected by the abnormal colour of the timber, by the transverse fractures of the fibres on longitudinal sawn faces, and by lifting the fibres with the point of a pen-knife, when, if the timber is decayed, the fibres will snap, instead of pulling out in long splinters. The presence of decay is often visible on the ends of logs from its spongy appearance, as contrasted with the more fibrous nature of sound timber. Fungal attack usually extends beyond the

visible area of decay and apparently sound timber immediately adjacent to decayed zones should be suspect. Provided timber is properly selected, and kiln seasoned so that any hyphae present in the wood are killed, the wood-rotting fungi which attack living trees need not concern the timber user. By far the most serious wood-rotting fungi are those which cause **dry rot** in converted timber. Several distinct fungi are responsible, although the majority of cases of serious damage in this country are due to the activity of a single species.

Merulius lacrymans.—This fungus is the commonest cause of dry rot; it is able to attack rather less damp timber than most other species. It forms masses of white hyphae which, when growing actively, produce drops of water which assist in maintaining adequate supplies of moisture for fungal growth. The attacked timber is friable, light in weight, and dry.

The conditions essential to fungal growth are:

(1) Food supplies,
(2) Adequate moisture,
(3) Suitable temperature,
(4) Air (oxygen) supplies.

In normal circumstances the growth of fungi in wood under service conditions is dependent solely on the presence of adequate moisture. Hence, the most effective method of eliminating wood-rotting fungi is to use sound, seasoned timber free from fungal infection in the first place, and to maintain efficient ventilation so that the timber will not be exposed to damp conditions subsequently. Once rot has got into wood it is important to take active measures immediately. These consist in removing and burning all infected wood and replacing it with only sound, preferably kiln-dried, material. Steps must also be taken to remedy conditions so that infection will not be repeated, and where it is impossible to ensure the maintenance of dry conditions in the future, the wood should be poisoned, *i.e.*, treated with a wood preservative.

The proper handling of dry rot and other fungal problems is a matter for the expert, since it is imperative to identify the causative agent to ensure the adoption of the most effective control methods. Several pamphlets describing the different destructive agents have, however, been issued by the Forest Products Research Laboratory, Princes Risborough, which should enable the layman to tackle the more simple cases himself.

Sap-stain fungi, of which **blue stain** in pine and other softwoods is probably the most common, are of little practical importance in constructional timbers although they may show through and spoil paint finishes in joinery work. These fungi can be eliminated by rapid conversion and seasoning of timber after felling, and by the maintenance of good ventilation subsequently.

Worm in Timber.—The damage known as **worm** in this country is the result of insect activity, but in salt water, teredo or ship-worm, and a form of wood-louse belonging to the crustacean family, are responsible for damage of this type. Insects tunnel in timber, spoiling the appearance of exposed faces, and if the tunnels are numerous they may so reduce strength properties as to make the wood valueless. Some insects only attack living trees or newly felled logs, some only seasoned wood, and others only the sapwood of certain species. In consequence, the presence of insect damage is not in itself necessarily a cause for alarm : the damage may be of the first type and therefore of no consequence in seasoned timber beyond the disfigurement caused. Moreover, some insects commonly associated with timber are of no importance, because they do not attack it. For example, everyone is familiar with the land form of wood-louse : small oval-shaped insects that roll up into balls when touched. They are to be found under any piece of timber that has been left lying about out-of-doors, or in a cellar, for a few days. Although probably the most familiar insect associated with timber, they are of no practical importance, as they do not attack wood. At most they are an indication that storage

conditions are not good, and may lead to infection by wood-rotting fungi. On the other hand, dangerous pests are often overlooked because their insignificant appearance causes them to escape notice.

No doubt most readers will recall having kept caterpillars in their youth. They will remember that the caterpillar had to be fed before it turned into a chrysalis, and eventually emerged as a totally different looking creature—a gaily coloured butterfly or a more sombre moth. A few readers may not have stopped to question how the caterpillar originated, but the others will know that butterflies and moths lay eggs from which caterpillars are hatched. So with beetles, the adults lay eggs from which small maggot- or caterpillar-like creatures, called **larvae**, are hatched. These are called " worms " in the timber trade. The larvae, after feeding, go through a resting, or chrysalis, stage called **pupation**, and emerge as adult beetles, thus completing the cycle. The four stages from beetle round to beetle are called a **life cycle**.

A study of the life cycles of different kinds of beetles is important in selecting methods of control. Some beetles are destructive in the larval, or feeding, stage, and others do more damage as adult beetles. In the former case the larvae feed on wood, either the substance of which the cell walls are made, or the contents of those cells, and in the latter case they feed on a fungus, introduced by the beetle at the time of egg-laying, which obtains its nourishment from the wood. Tunnelling, which is the destructive work of beetles, is done by the larvae in the first type, and by the adult beetle in the second. With the first, control must aim at killing the larvae before they get in, or rendering the wood unfit for food; with the second, the beetle must be denied entry to the wood, or conditions made such that the fungus cannot survive.

The duration of the life cycle is a second important factor: in some insects it is completed in a few months, but in others it may last two to three years. If the life cycle is a long one infection may have occurred, and the destructive

agency been at work, for a considerable time before it is discovered. On the other hand, the shorter the life cycle the more frequently must sterilizing treatments be repeated, if they do not confer immunity from re-infection. Treatments should be applied when the pest is in its most vulnerable state.

The different types of insects, the means of their identification, and the methods of control, are discussed fully in various pamphlets and bulletins issued by the Forest Products Research Laboratory, Princes Risborough, The Forestry Commission, and other Government organizations. Below, the groups of insects of particular importance to timber users are enumerated, and briefly described.

I. FOREST AND MILL-YARD PESTS

(1) *Longhorn Beetles and certain Moths.*—The larvae of these insects hatch from eggs laid in the crevices, or just under the bark, of living but usually unhealthy trees, or newly felled logs. They tunnel into the wood, feeding on the wood substance. The galleries are $\frac{1}{8}$ to 1 in. in diameter, and are packed with coarse or fibrous wood-dust. The damage done by these insects is considerable, but they are essentially a forest problem. The larvae can continue to live, and extend their tunnels, in seasoned wood, but infection can only occur in green timber; that is, infection will not be carried by the larvae to dry, clear stock. Rapid extraction and removal of bark of susceptible timbers, and heat sterilization of infected wood should secure adequate protection.

(2) *Pin-hole Borers.*—The adult beetles tunnel into living trees and newly felled logs, and lay their eggs. At the same time they introduce a fungus into the galleries on which the larvae feed. The galleries are $\frac{1}{50}$ to $\frac{1}{8}$ in. in diameter, and run across the grain. They are usually empty, but may become plugged with resin or other compounds: the walls are stained black, and the holes may be surrounded by an elongate-oval area, discoloured by the fungus. Pin-hole

borers ruin the appearance of considerable quantities of timber, and the galleries may be so numerous as to reduce strength, but attack does not continue in, nor can it spread to, seasoned timber, because the fungus on which the larvae feed requires moisture. Moreover, the whole of the gallery system of these borers is constructed by the adult beetle, so that the damage is done before the timber gets to the mill. In the circumstances the timber merchant can purchase infected timber without fear of the attack becoming any worse than it is at the time of purchase. Wormy grades of mahogany, lauan, seraya, and meranti, contain damage of this order. The shot-holes referred to in the Empire grading rules [1] are due to the same type of beetle, referred to as pin-hole borers here, and are distinct from shot-hole borers of trade terminology in this country and America.

(3) *Borers responsible for Damage of the American Sweet Chestnut "Sound-wormy" Type.*—Two families of beetles, causing damage somewhat similar to that of pin-hole borers, attack certain timbers in an unseasoned condition. The larvae do the tunnelling, feeding on the wood. The galleries vary considerably in diameter; they are usually not stained, and are packed with wood-dust. Provided appearance and reduction in strength are of secondary consideration these borers are unimportant, because their attack ceases, and cannot recommence, in seasoned timber. Green material stored in close proximity to infected timber might, however, become infected. Rapid conversion and drying after felling is an effective method of controlling these insects.

II. PESTS OF SEASONING YARDS AND SEASONED TIMBER

(1) *Lyctus, or Powder-post Beetles.*—These beetles lay eggs in the pores of wood, and the larvae tunnel about, feeding

[1] *Grading Rules and Standard Sizes for Empire Hardwoods*, prepared by the Advisory Committee on Timbers, Imperial Institute. See also page 158.

on the starch contained in the storage cells. The attack is confined to the sapwood of certain hardwoods; [1] it does not occur in the heartwood of any species, nor the sapwood of softwoods. Infection occurs in partially- or fully-seasoned timber. The holes are similar in size to those of the smaller pin-hole borers, but they run in a vertical direction, and are filled with a flour-like powder. The outer shell of a timber is often left intact, and only the exit holes of mature beetles, and the fine dust, are evidence of attack. These beetles are responsible for enormous damage to the sapwood of susceptible timbers. Control can be effected by removal, and burning, of all sapwood of susceptible species, but this course is often not practicable. Alternatively, infected timber may be sterilized by kiln treatment at 130° F. and 100 per cent. relative humidity for a period of 1½ hours or more, depending on the thickness of the stock. Such a treatment destroys all stages of the insect, but does not eliminate the risk of re-infection. Infected structural timbers should be given a liberal dressing of hot creosote. To reduce the risk of infection in timber yards and factories the Forest Products Research Laboratory recommends the regular inspection of stocks twice yearly in March and October, clean yards (*e.g.*, sapwood waste should not be allowed to accumulate), and the use of only softwood or heartwood piling sticks. In indoor uses it is recommended that all sapwood of susceptible species be eliminated from structural timbers, panelling, and furniture.

(2) *Bostrychid Powder-post Beetles.*—Except for differences in size of exit holes, the damage done by these insects is similar to that of the previous group. That is, the larvae tunnel in partially- or recently-seasoned sapwood of certain hardwoods, reducing the wood to a flour-like dust. The methods of control are similar to those for *lyctus*, or powder-post beetles.

[1] Attack is confined to timbers with pores large enough to admit the ovipositor (egg-laying tube) of the female beetle. In consequence, fine-textured woods, *e.g.*, beech, are immune.

III. PESTS OF WELL-SEASONED, OLD WOOD

(1) *Furniture Beetles.*—The natural home of this pest is out-of-doors, in decayed trees and posts, but it will attack well-seasoned timber of softwoods and hardwoods. The damage is done by the larvae which hatch from eggs laid in cracks in the wood. They travel along the grain for a time, but as they feed and grow they tunnel in all directions, filling their galleries with loosely-packed, finely-granular, wood-dust. In small articles the damage is not confined to sapwood, but in beams, etc., it usually is. Control can be effected by repeated applications of suitable preservatives. To reduce the risk of infection it is recommended that timber free of sapwood be used, and that care be exercised in the purchase of second-hand wooden articles lest they are a source of infection to unattacked material.

(2) *Death-watch Beetles.*—This pest belongs to the same family as the furniture beetle, and its natural home is rather similar. The beetle lays eggs in crevices, cracks, or old exit holes, and the larvae do the damage by tunnelling in, and feeding on, the wood. Attack is usually confined to old timbers of several species of hardwoods, but it has been known to spread to softwood timbers adjacent to infected hardwoods ; it is not limited to the sapwood. Adequate moisture, and the presence of fungal decay, are conditions favourable for infection. The galleries, about $\frac{1}{8}$ in. in diameter, are filled with coarsely-granular dust. Removal of decayed wood, increased ventilation, and the regular and repeated application of suitable preservatives, are recommended for subduing attack. The Princes Risborough Laboratory points out, however, the necessity of a thorough inspection by experts before any curative steps are taken. Care must be taken that wood introduced during repairs is free from infection, and to ensure this well-seasoned timber free from sapwood, and treated with a preservative, is recommended.

From the above notes it will be apparent that the mere

presence of a worm-hole may be of no greater significance than the slight disfigurement it causes ; certainly it is often less harmful than many a knot. On the other hand, the discovery of a little dust on a board may indicate the urgency of most stringent action. The problem is worthy of due consideration, and all who handle timbers, particularly those concerned with hardwoods, should make themselves acquainted with the type of damage caused by the different kinds of insects, so that they may be in a position to detect those that are still a source of danger from those that are not able to cause further damage.

CHAPTER XII

THE PRESERVATION OF WOOD

GENERAL PRINCIPLES

ALTHOUGH no timber is immune to deterioration and ultimate disintegration if exposed for a sufficiently long period to ordinary atmospheric conditions, the serviceable life of individual pieces varies considerably, depending on the species concerned, the amount of sapwood present, the use to which the timber is put, and the situation and atmospheric conditions to which it is exposed. For example, sound wood has been recovered from the Egyptian tombs and from piles driven into mud hundreds of years ago; in these, and similar instances, preservation is to be attributed to protection from the atmosphere rather than to inherent durability. There is little doubt that many species generally considered non-durable would last almost indefinitely under such conditions. The persistence in the forest for several centuries of sound stumps of western red cedar is, however, only explained by the natural durability of that species when exposed to ordinary atmospheric conditions. On the other hand, even the most durable timbers may last only a few years if placed in a warm, damp, and badly-ventilated, position.

The principal causes of deterioration of wood in service (as distinct from deterioration during seasoning) are fungal infection, termite and other insect- or marine-borer attack, mechanical failure, and fire. The resistance of a timber to these agencies may frequently be increased by the application of a suitable chemical, which acts as a preservative. One or two substances were used for this purpose as long ago as

Roman times, but the extensive application of preservatives is a development of the last hundred years. In practice preservatives are usually applied to non-durable timbers so as to render them sufficiently resistant to the agencies of deterioration to warrant their replacing naturally-durable, but more expensive, timbers. The chemicals used are legion, and several methods of application are advocated. The selection of the most suitable chemical and method of treatment are of the utmost importance and must be based on a thorough understanding of the scope and limitations of preservative treatments; none confers complete immunity, and a treatment suitable for one particular set of conditions may be useless for others.

FIRE PROOFING

Wood is highly combustible but non-inflammable ; that is, although under suitable circumstances any wood may be burnt to ash, timber is, comparatively speaking, not readily ignited. This statement applies equally to the most resinous species and to those furnishing the poorest firewood. Certain timbers are classed as fire-resistant under the London County Council Bye-laws ; such timbers have withstood a standard flame test, or have shown themselves capable, under certain conditions, of not passing on a fire during a definite, arbitrary period.

The various processes of "fire-proofing" timber do not render it incombustible, but appreciably increase the fire-resistant or retardant properties. Fire-proofing processes consist of introducing into wood chemicals, *e.g.*, monobasic phosphate of zinc followed by an ammonia gas treatment. The chemicals may be applied either hot or cold, with a brush, by dipping, or under pressure ; because of the better penetration achieved, pressure treatments are to be recommended wherever practicable. Some fire-proofing chemicals have the added advantage of being toxic to insects and fungi, thereby combining two processes in one operation. The

different chemicals that have been used cannot be discussed in detail here, but the essential qualities of a fire-proofing substance may be noted; namely, ability to reduce flaming and glowing, thereby retarding the spread of a fire, good penetration, and, if the treated timber is to be used out-of-doors, resistance to leaching.

MECHANICAL WEAR OR FAILURE

In many situations the life of timber is limited by mechanical wear, against which ordinary preservative treatments are ineffective. The serviceable life may sometimes be extended, however, by attention to design, and selection of the most suitable timber in the first instance. Experience has shown, for example, that for flooring blocks, subjected to an abrasive action, quarter-sawn (edge-grain) timber has a longer life than flat-sawn timber, and paving blocks usually last longer when laid on a resilient, rather than on a rigid foundation. The corrosive action of certain chemicals is sometimes regarded as a special form of mechanical wear. Timber in factories manufacturing such chemicals is bound to be affected in time, as are wooden cases of storage batteries. Ordinary preservatives are ineffective against such forms of corrosion, but protection may be afforded by impermeable coatings of wax or other suitable material. A few timbers, *e.g.*, abura, lignum vitae, are relatively acid-resistant, and should be employed in preference to the more usual constructional timbers in positions subject to the action of corrosive substances.

FUNGI AND INSECTS

Wood preservatives are used mainly to increase the resistance of timbers to insect attack and fungal infection; they are also used to some extent in the elimination, or control, of attack in progress, an aspect already referred to in Chapter XI. Many substances have been tried as wood preservatives; some have proved excellent, others quite worthless.

THE PROPERTIES OF PRESERVATIVES

In selecting a preservative, the importance of bearing in mind the particular job in hand cannot be over-stressed. For example, a substance that is readily soluble in water may be excellent for indoor use but worthless for outside work, and, conversely, a substance with a pronounced odour may be quite satisfactory for outdoor work but totally unsuitable for indoor use. Extravagant claims on behalf of proprietary products should always be accepted with reservation ; even the best preservative merely prolongs the life of wood, it does not confer immunity from attack for ever.

The ideal wood preservative has yet to be found, but the properties ascribed to such a substance form a useful basis for comparison. It should be : [1]

1. Highly poisonous (toxic) to fungi and insects.
2. Readily penetrating into wood.
3. Chemically stable (*i.e.*, not readily volatilized or easily decomposed, and, for outdoor use, not easily leached out).
4. Easy to apply and not dangerous or harmful to those applying it or subsequently handling the treated timber.
5. Non-deleterious effect on the timber treated.
6. Cheap and readily obtainable.
7. Non-corrosive to iron, steel, or other materials, according to circumstances.
8. Fire-resistant, or at least not increasing the inflammability of wood (this is of secondary importance in timber for fence posts, gates, and other similar purposes).

The following additional qualities are sometimes important, especially for indoor application :

[1] Compiled from *The Preservation of Timber*, Trade Circular No. 27, Commonwealth of Australia, and "The Toxicity of Preservatives against Wood-destroying Fungi", by K. St. G. Cartwright, *Forestry*, vol. v. p. 139, 1931.

9. Odourless.
10. Colourless and free from effect on subsequent painting or finishing of the treated timber.

The first three properties are essential qualities of any wood preservative, and the remainder are of diminishing importance, according to circumstances.

In general, preservatives may be divided into two broad classes: (*a*) The tar-oil group (*e.g.*, creosote), the principle toxic agencies of which are phenol bodies, although some are poor in proved toxic substances, and probably owe their protective qualities to contained waxes. (*b*) Salts, *e.g.*, zinc chloride, silico fluorides, arsenic salts, and other water-soluble compounds, and a few substances soluble in other solvents than water.

In addition to these, preservatives consisting of mixtures of the two classes are sometimes used, and volatile substances the vapour of which is the toxic element.

The tar-oil group of preservatives is most widely used for outdoor work, where a sometimes pungent odour and inability to take paint are immaterial, but non-leaching qualities are of the greatest importance. The water-soluble salts, on the other hand, are more suitable for interior use, since they possess just those qualities which the tar-oil group lack (*i.e.*, they are colourless, odourless, able to take paint, fire-resistant or at least do not increase the fire hazard), although suffering from the disadvantage of being readily leached out, and often of being more costly. Provided the best of either class is used there is little difference in toxic value, but better penetration is often more readily secured with a soluble salt. The products of prolonged coal-tar distillation consist of high-boiling tars of low toxic value, and when purchasing creosote it is especially important to see that it conforms to some definite specification, *e.g.*, that of the British Standards Institution or the Standards Association of Australia.

THE APPLICATION OF PRESERVATIVES

Having decided on the preservative, the problem of getting it into the wood remains to be settled. The three principal methods are (1) brush coating, (2) dipping, and (3) pressure treatments. But just getting some definite quantity of a preservative into a timber is no guarantee that the treatment will be satisfactory; depth and uniformity of penetration are of the utmost importance. Uniformity of penetration is dependent largely on the anatomical structure of wood: sapwood absorbs preservatives more readily than heartwood, the late wood of softwoods better than the early wood, and timber of some species more readily than that of others—*e.g.*, Scots pine (red deal) is much easier to impregnate than Douglas fir, apitong than lauan. Depth of penetration is only important where checks are likely to develop after treatment, otherwise the thinnest complete covering is all that is necessary: wood below a treated skin is, however, bound to be exposed sooner or later.

Certain general principles should be observed whatever the nature of the preservative or method of treatment. For example, because of its better absorptive powers, sapwood should be retained, and in larger-sized timbers those with a complete outer layer of sapwood should be selected for treatment in preference to those with one or more heartwood faces. Better penetration is obtained with hot than with cold methods of application, and, except with chemicals that decompose on heating, preservatives should be applied hot wherever practicable. Air-dry wood absorbs preservatives better than green wood, so that timber should be seasoned before treatment; this precaution also ensures that any checking will occur before, and not after, treatment, thereby avoiding the exposure of wood below the depth of penetration of the preservative. For the same reason all trimming and boring should be done before treatment.

Brush Coating.—Brush coating is the simplest method of applying a preservative, but it is also the least efficient. If,

however, two or more coats are given, and the treatment is repeated every two or three years, some measure of protection is obtained, particularly with interior woodwork which is not exposed to mechanical wear. The method should, however, only be used where alternative treatments are impracticable, with preservatives with good penetrative qualities, and with timbers of high absorptive powers.

Spraying and Dipping.—Spraying is better than brush coating, but dipping is appreciably more effective than either, because the wood is in contact with an excess of preservative for the duration of the dipping process. If this is sufficiently long, and the absorptive powers of the wood are good, a considerable amount of preservative may be taken up.

Open Tank.—A special form of dipping (really a modified pressure treatment), known as the **open tank** method, is particularly effective, and, except that it is more wasteful of the preservative than certain pressure treatments, gives excellent results with timbers of good absorptive powers. The method requires a bath, with some form of heating apparatus, in which the timber to be treated can be completely immersed. The timber is submerged in the cold preservative, which is then gradually heated to a temperature of 160 to 200° F., according to the type of preservative and the absorptive powers of the timber. The temperature is maintained for 2 to 4 hours, after which the preservative is allowed to cool, with the timber still immersed. Heating causes the air in the cells of the wood to expand, some being expelled, and as cooling begins the air contracts, sucking in the preservative to take the place of the air lost. In this way larger amounts of preservative are taken up by the wood, and penetration to a greater depth is obtained, than by simply dipping the timber in either hot or cold preservative.

The simplest form of open tank is a container that can be heated by external firing, but, because of the risk of the preservative catching fire, steam-heated coils inside the tank are much to be preferred. Various refinements, such as mechanical loading devices and separate cooling tanks, are

sometimes introduced, but these are not essential. The method is to be recommended only where the quantities of timber to be treated are insufficient to justify the capital outlay on the more expensive, but more efficient, plant necessary for pressure processes.

Pressure Processes.—The most effective method of treating timber is a pressure process which forces the preservative into the wood. In this way penetration is obtained to a considerably greater depth than is possible by any other method. The open-tank method is, in a sense, a pressure process, but the pressure is of necessity less than one atmosphere. Using closed retorts, high temperatures and pressures of several atmospheres can be employed, the only limitation being the risk of mechanical damage to the timber. For this reason temperatures much in excess of 200° F., or pressures greater than 200 lb. per square inch, are rarely used.

A pressure plant consists of a retort fitted with a door which can be hermetically sealed, a supply of steam for raising temperatures, and hydraulic pressure pumps for controlling the pressure inside the retort. The oldest pressure process, introduced in 1838, is the **Bethel** process, which is still in use today. After loading, hot preservative is run in, and a pressure is gradually built up. When an excess of preservative has been injected, the pressure is released and the surplus liquid drawn off. A common modification of the Bethel process is the application of a vacuum to the timber before running in the preservative. This, it is claimed, by drawing the sap from the cell cavities, facilitates the subsequent entry of the preservative into the wood; technical opinion does not support this claim, however, holding that the vacuum period generally used is too short to affect the issue. The vacuum, however, serves two purposes: by increasing the pressure differences to which the timber is subjected, there is an increase in the pressure causing impregnation, and, by establishing a vacuum in the retort, filling is facilitated, particularly if the storage tank is at a lower level than the treating cylinder.

The Bethel process and its modifications are known as **full-cell** processes ; that is, if completely successful, not only is the preservative injected into the cell walls, but the cell cavities also are filled. Except with readily-leachable substances, and timbers of low-absorptive powers, an excess of preservative occupying the cell cavities is wasteful. To overcome this objection a pressure treatment, known as the **Rueping process**, has been devised. Before the hot preservative is admitted into the treating cylinder an initial air pressure is established which compresses the air in the cell cavities of the timber. The hot preservative is then introduced and a still higher pressure is built up within the retort until an excess absorption is obtained. The pressure is then reduced to atmospheric, so that the air compressed in the cell cavities expands and ejects the surplus preservative. In this way a relatively-deep impregnation is secured with a smaller net absorption of preservative, compared with full-cell treatments. A modification of the Rueping process, known as the **Lowry process**, employs an initial, atmospheric-air pressure and a vacuum at the end of the run to extract surplus preservative. The amount extracted is comparatively small compared with that expelled at the end of the Rueping process.

In another pressure treatment, the **Boulton** process, an initial vacuum is applied to the timber while submerged in the heated preservative. This reduces the boiling point of the water contained in the wood, enabling it to evaporate at a temperature below 212° F. In this way considerable drying of the timber can be effected at lower temperatures with consequently less damage to the wood.

Incising.—The relative ease with which different timbers absorb preservatives varies appreciably. Beech and Scots pine sapwood can be completely impregnated under pressure in 1 to 3 hours, but a similar treatment of Douglas fir, larch, or oak heartwood, would not effect complete impregnation in several days. Moreover, a more severe treatment, using higher temperatures and pressures, does not overcome the

difficulty, but merely secures increased absorption in patches. Various attempts have been made to solve the problem of treating refractory timbers and, of these, an operation known as **incising** has proved the most successful. The process consists in making incisions parallel to the fibres to the depth of penetration required, and spaced sufficiently close together that the lateral spread of the preservative will cover the surface of the timber uniformly and completely. By this means an increased absorption of 30 to 60 per cent. has been obtained with Douglas fir sleepers.

Other Methods of Treatment.—The foregoing pages have outlined the more important methods of applying wood preservatives that are in general use, but one or two other methods are of interest. In the **Boucherie** process, used in France for the treatment of telegraph poles, the preservative (copper sulphate solution) is applied to the bottom of a log, fixed in a vertical position, by means of a cap which is connected to a pipe leading from an elevated tank containing the preservative. A hydrostatic head of several feet is obtained, which forces the liquid through the timber, the process being completed when the preservative appears at the top end of the log.

The impregnation of fence posts and telegraph poles *in situ* by diffusion has been tried in Germany. The preservative is injected, in paste form, at several points and spreads by diffusion through the wood: good penetration has been secured by this means with wet timber. The same principle is involved in the attempts to introduce preservatives into timber *before* the tree is felled, but the method is still in an experimental stage.

The impregnation of non-durable timbers with the alcohol extractives (infiltrates) of durable woods has not met with success, although it is known that these substances are responsible for rendering certain timbers naturally durable. The reason for this is, no doubt, that the infiltrates or extractives are more intimately associated with the cell-wall structure than can be reproduced by artificial impregnation.

CHAPTER XIII

GRADING OF TIMBER

GENERAL PRINCIPLES

THE inherent variability of natural products presents many difficulties in their marketing, particularly in these days when competition and mass production have brought a high degree of uniformity in rival materials. Timber producers have long found it advantageous to study this variability and some have evolved sets of rules and grading marks which have come to be regarded as a guarantee of high quality. Unfortunately in some countries there is little standardization of the material of different producers, and some producers are found to be inconsistent in their grading over a period of years. In the interests of trade, attempts have been made on the part of various Governments to standardize the grading of many natural products, but timber has generally escaped such beneficial action, and in this country there has been no concerted effort on the part of the industry as a whole to introduce grading rules.

A set of rules applicable to natural products must of necessity be to some extent arbitrary, and will invariably be subject to the personal factor in interpretation. This accounts in part for the delay in the universal acceptance of grading rules for timber. The first set of grading rules was issued as long ago as 1764, when Sven Alversdon of Stockholm defined four grades of Swedish pine, *i.e.*, " best ", " good ", " common ", and " culls ", and timber has been graded for many years in America and Canada in accord-

ance with special, written grading-rules, agreed on by the different sections of the industry as a whole.

THE BALTIC TRADE

Before discussing the standardized rules in use it will be as well to consider the position in those countries that have not adopted standard rules. Chief of these, as far as the British market is concerned, are the Baltic countries, including Russia, which supply the bulk of the carcassing and joinery timber used in Britain. Grading in these countries is in essentially the same state as it was thirty years ago, with the important difference that there has been a marked falling-off in quality of timber exported. Every manufacturer follows his own rules, the actual grading, or **bracking** as it is called, being done by men with a lifelong association with timber. The grades used are 1sts, 2nds, 3rds, 4ths, 5ths, and 6ths, and "unsorted", the last being a mixture of grades better than 5ths. The bulk of the timber from the Scandinavian countries is graded as "unsorted" or 5ths, and that from Russia as 1sts, 2nds, or 3rds. In the Scandinavian countries heavy cutting in the past has necessitated the opening-up of new areas of forests, with the result that the nature of the raw material coming to the mills has changed. Shippers who have been in the habit of obtaining supplies from one locality year after year, are obliged to go to different localities each year, and the brackers, with only empirical experience to guide them, are dependent on heir own judgement for maintaining continuity of quality. In consequence, whereas formerly the purchaser could depend on particular shipping-marks to secure the type of timber required, nowadays the produce of successive years, shipped under the same marks, may vary appreciably.

The practice of architects, surveyors, and engineers, of specifying their requirements in considerable detail, does little to alleviate the position. The specifications

frequently impose ridiculous limitations. For example, the contractor may be called on to supply timber "straight in the grain, free of sap, knots, and other defects", and clauses are sometimes added to exclude "dead" wood and "blue stain". Such specifications are, and always have been, impossible of fulfilment. Timber is a natural product and is never absolutely free from defects or minor blemishes, many of which impair its utility but little. Some latitude, for example, in straightness of grain is permissible for most purposes, the exclusion of sap is rarely essential and is frequently impossible, and knots cannot be avoided except in timber from the outside of really large trees; for many purposes "blue stain" is unimportant, and, as 95 per cent. of the tissue of all living trees is dead before the trees are felled, it is difficult to see that the death of the remaining 5 per cent. will make much difference to the value of the timber. There is, of course, the risk that, as dead trees are more liable to attack by fungi and insects than living trees, their timber may be a source of infection to sound stock, but this can be guarded against by insisting on sound wood. Ample experimental evidence exists to show that *sound* wood from dead trees is in no way inferior to *sound* wood from living trees, and as it is drier it may be actually superior. In effect, the average timber specification is a dead letter; but whereas formerly it could safely be ignored, today the insistence on some form of specification is essential. Specifications, should, however, be capable of fulfilment and so worded as to protect the real interests of the client.

THE AMERICAN TRADE

The practice in the U.S.A. and Canada is for the producers of different classes of timber to form themselves into Associations, and for the Associations to issue grading rules for their products. Thus in the U.S.A. nearly all hardwood timber is graded in accordance with the rules of one or

other of two lumber associations, the National Hardwood Lumber Association or the Hardwood Manufacturers' Association. Softwoods, being more widely distributed, are handled by a larger number of associations, each with its own rules. For example, there are the Southern Pine Association, the Northern Pine Association, the Southern Cypress Manufacturers' Association, the Californian Redwood Association, and the West Coast Lumberman's Association; each is situated in a different geographical region, and handles different timbers. In Canada the Associations are fewer, but the principles remain the same. Douglas fir, Western hemlock, Western spruce, and Western red cedar, for example, are graded in accordance with the grading rules adopted by the British Columbia Lumber and Shingle Manufacturers, Limited, and similar bodies deal with the softwoods and hardwoods of Eastern Canada.

In order to ensure uniformity of grading as far as possible, several of the larger associations employ a corps of men who grade the produce of all the members. In this way one manufacturer cannot steal a march on his competitors by lowering the quality of his goods, and the purchaser is assured of getting the same minimum quality wherever he makes his purchases. There is, of course, still room for individuality by supplying something better than the minimum standards, or by attending to detail not specifically covered by the grading rules.

THE EMPIRE TRADE

Attempts to introduce many new timbers from our tropical colonies on to the United Kingdom market have been handicapped by the absence of recognized standards of quality. This led to official action, and a sub-committee of the Imperial Institute Advisory Committee on Timbers was appointed to examine the position. As a result grading rules and standard sizes for Empire hardwoods have been evolved on the American principle and published by the

Imperial Institute. The rules are divided into three sections :

A. Hardwoods from countries other than Canada and New Zealand.
B. Canadian hardwoods.
C. New Zealand hardwoods.

Only those in section " A " are fully dealt with, those in " B " and " C " being graded according to the " rules of the National Hardwood Lumber Association ". In section " A " three main divisions are made :

I. *Standard Grades* (two qualities).
II. *Wormy Grades* (three qualities).
III. *Grades for Shorts, Squares, Strips, Quarter-sawn stock* (seven qualities).

It remains to be seen how these rules will work out in practice, because they are being applied in the main by officials who lack the lifelong acquaintance with timbers possessed by the professional graders in America. On the other hand, it is a step in the right direction, and the method of application of the rules has the same advantage as that of American practice in that grading is done by an independent body, and not by individual producers.

STANDARDIZED RULES

Apart from the co-operation necessary between producers to make standardized rules workable, two conditions are desirable for their efficient working. In the first place the grades should be so balanced that they fit the requirement of the market and in the second there must be a proper appreciation of the significance of defects.

Present-day grading rules, such as are used in America, Canada, and a few other countries, have been evolved during the last forty years. They differ in details, but all are based on a single general principle, namely, the allocation of numerical

values to every kind of defect or blemish, with a limit to the total score allowed in each grade per unit of area or volume of timber. Two or more minor defects are counted as one more serious defect, the usual practice being to define certain **standard defects** and to regard minor ones as a fraction of a standard defect and more serious ones as equivalent to two or more standard defects.

The significance of defects depends on the purpose to which timber is put, and on the kind of timber. For example, blemishes that mar the appearance of wood but do not reduce its mechanical strength are unimportant in structural timbers and, conversely, defects which reduce the strength properties without appreciably spoiling the appearance are serious. With decorative timbers the reverse is true, and a defect that reduces strength but does not disfigure timber is less important than one that has little effect on mechanical properties but is relatively conspicuous. These conditions can be allowed for in grading rules by assessing the same type of defect on a different basis according to circumstances. Sometimes, moreover, features that in themselves are neither defects nor blemishes influence the utilization of wood and must be considered in grading. An important instance is the size of pieces; length may be important in flooring strips although unimportant for table tops and, conversely, width may be necessary in the latter but of little significance in the former. Grading rules take all these points into consideration, and many more besides. Timber may be graded on both sides, or on only one, according to whether, in position, both or only one side is visible. It has already been mentioned that grading rules are necessarily arbitrary, and that they permit of some personal latitude in their application, but to obviate disputes it is usual to define the allowable latitude by inserting a clause to the effect that only a certain minimum proportion of a consignment shall be up to or better than the standard of a particular grade. This allowance is usually round about 5 per cent.

In practice a good man eliminates the laborious business

of totting up defects and arrives at the grade almost instantaneously. Moreover, it is found that whereas two experienced graders may differ somewhat as to the grade of individual pieces of timber, when whole consignments are judged, the quality is relatively even. When grading by arbitrary rules it is important to remember that the aim is to standardize quality, and this end is more likely to be achieved by following the spirit of the rules rather than the strict letter.

SPECIFICATIONS

The existence of standardized rules does not obviate the necessity for specifications to define the purchaser's precise requirements, but in the absence of such rules the role of specifications is even more important. They serve the dual purpose of delimiting a client's reasonable demands and the contractor's legitimate liabilities. The simplest course is to specify a particular grade of timber and to add clauses to meet the special requirements of a particular case. This is possible only when recognized grades of the required timber exist—a condition seldom obtaining at present in Britain. Alternatively, the grade may be more vague and the conditions more explicit. For example, if Baltic timber is required, "unsorted", Finnish pine from the Kotka or Uras districts should fulfil all reasonable requirements for high-class carcassing work, and 2nd-quality Archangel would be probably entirely satisfactory for joinery purposes, although different consignments might vary appreciably. Moreover, the restriction as to district is unfair on manufacturers as a whole, and it might result in the payment of unnecessarily high prices.

Other conditions than quality are of practical significance. Chief of these are the moisture content of the timber and the condition of the building at the time the timber is installed. Requirements as to moisture content are specified on page 94, but equally important is the state of dryness of the building. It is sometimes economical to install temporary

heating apparatus before fixing the finishings, and when this course is impracticable such work should be postponed for at least three months after the roof has been fixed. More latitude than is usual might be allowed in the inclusion of sapwood and "blue stain" in softwoods, and the conditions as to straightness of grain may often be relaxed with safety. On the other hand, boxed hearts in joists, and the occurrence of large knots in the middle of a span, should be rigidly excluded. The aim should always be to ensure that the timber is equal to the demands placed upon it, and in the ordinary course of events properly selected, sound timber will do all and much more than is required of it.

APPENDIX

LIST OF BOTANICAL EQUIVALENTS OF COMMON OR TRADE NAMES USED IN THE TEXT

NOTE.—In many cases it is not possible to give a single botanical name because the latter is often applied to the timbers of more than one species or even genera ; such cases are given below as " spp.", no attempt being made to list all the species that may provide commercial supplies.

abura = *Mitragyna stipulosa* Kuntze
alder = *Alnus glutinosa* Gaertn.
apitong = *Dipterocarpus* spp. (Philippines)
ash = *Fraxinus* spp.
ash, mountain = *Eucalyptus regnans* F. Muell.
balsa = *Ochroma* spp.
beech = *Fagus sylvatica* L.
birch = *Betula* spp.
boxwood = *Buxus sempervirens* L.
camphor wood, Formosan = *Cinnamomum camphora* Nees et Eberm.
cedar = *Cedrus* spp.
cedar, cigar-box = *Cedrela odorata* L.
cedar, Honduras = *Cedrela mexicana* Roem.
cedar, western red = *Thuja plicata* D. Don
chestnut, American sweet = *Castanea dentata* Borkh.
chestnut, sweet = *Castanea sativa* Mill.
coachwood = *Ceratopetalum apetalum* D. Don
cornel = *Cornus florida* L.
deal, Baltic = *Pinus sylvestris* L.
deal, red = *Pinus sylvestris* L.
Douglas fir = *Pseudotsuga taxifolia* Brit.
ebony = *Diospyros* spp., *Maba* spp.
ekki = *Lophira alata var. procera* (A. Chev.) Burtt Davy

elm = *Ulmus* spp.
elm, wych = *Ulmus glabra* Hudson (non Miller)
fir = *Abies* spp.
fir, Douglas, *see* Douglas fir
gurjun = *Dipterocarpus* spp. (Andamans, Burma)
hazel = *Corylus avellana* L.
hickory = *Hicoria* spp.
holly = *Ilex aquifolium* L.
hornbeam = *Carpinus betulus* L.
jarrah = *Eucalyptus marginata* Sm.
keruing = *Dipterocarpus* spp. (Malaya, Borneo)
larch = *Larix* spp.
lauan = *Shorea* spp., *Pentacme* spp., *Parashorea* spp. (Philippines)
lignum vitae = *Guaiacum officinale* L., *G. sanctum* L.
lime = *Tilia vulgaris* Hayne
logwood = *Haematoxylon campechianum* L.
mahogany = *Swietenia* spp.
mahogany, African = *Khaya* spp. and *Entandrophragma* spp.
mahogany, Cent. American = *Swietenia macrophylla* King
mahogany, cherry = *Mimusops heckelii* (A.Chev.) Hutch. and Dalz.
mahogany, Gaboon = *Aucoumea klaineana* Pierre
mahogany, Honduras = *Swietenia macrophylla* King
mahogany, Philippine = *Shorea* spp.
mahogany, Spanish = *Swietenia mahagoni* Jacq.
mansoni = *Mansonia altissima* A. Chev.
maple = *Acer* spp.
maple, Pacific = *Acer* sp.?
meranti = *Shorea* spp. (Malaya, Sarawak)
meranti, white = *Shorea* spp. (Malaya)
merbau = *Afzelia bakeri* Prain
mujua = *Alstonia congensis* Engl.
oak = *Quercus* spp.
oak, American white = *Quercus alba* L.
oak, Australian silky = *Cardwellia sublimis* F.v.M., *Grevillea robusta* A. Cunn.
oak, red = *Quercus rubra* L., *Q. borealis maxima* (Marsh.) Aske
oak, Tasmanian = *Eucalyptus obliqua* L'Hérit.
oak, Turkey = *Quercus cinerea* Michx.
pear = *Pyrus communis* L.

persimmon = *Diospyros virginiana* L.
pine, Columbian, *see* Douglas fir
pine, Oregon, *see* Douglas fir
pine, pitch = *Pinus rigida* Mill.
pine, Scots = *Pinus sylvestris* L.
pine, white = *Pinus strobus* L.
poplar = *Populus* spp.
redwood = *Sequoia sempervirens* (Lamb.) Endl.
redwood, Californian = *Sequoia sempervirens* (Lamb.) Endl.
rengas = *Melanorrhoea* spp.
rosewood, Indian = *Dalbergia latifolia* Roxb.
sandalwood = *Santalum album* L.
satinwood, East Indian = *Chloroxylon swietenia* DC.
satinwood, West Indian = *Zanthoxylum flavum* Vahl
seraya = *Shorea* spp., *Parashorea* spp. (Borneo)
seraya, Borneo white = *Parashorea* spp.
seraya, white = *Shorea* spp., *Parashorea* spp. (Borneo)
sneezewood = *Ptaeroxylon obliquum* (Thunb.) Radlk.
spruce = *Picea* spp.
spruce, sitka = *Picea sitchensis* Carr
sycamore = *Acer pseudoplatanus* L.
tallowwood = *Eucalyptus microcorys* F. Muell.
teak = *Tectona grandis* L.f.
tulip wood = *Liriodendron tulipifera* L.
walnut = *Juglans* spp.
walnut, Australian = *Endiandra palmerstonii* C.T. White
walnut, Nigerian = *Lovoa klaineana* Pierre ex Sprague
walnut, Queensland, *see* walnut, Australian
whitewood, American = *Liriodendron* spp.
willow = *Salix* spp.

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